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THE TEMPERATURE OF LAKES.

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READ AT THE ANNUAL CONVENTION, JUNE, 1895.

WITH DISCUSSION.

For several years past the author has published in his annual reports to the Boston Water Board the monthly temperatures at the surface, mid-depth and bottom of Lake Cochituate, the storage basins and distributing reservoir connected with the Boston Water Supply, together with the temperatures in the city mains. These tables are based on weekly observations made at the time of collecting samples for analysis, and as the temperature is not the principal object, and dependence is necessarily placed upon unskilled observers, the results cannot always be depended upon to the tenth of a degree, although they are so expressed. The observation of the correct temperature of water is a more difficult matter than is generally realized. Especially is this true at the bottom of a deep lake where it takes more than an hour to get the reading with mercurial thermometers to within a tenth

of a degree. With the thermophone a more accurate result is now obtained in a few minutes.

M. de Saussure, who was the first to take the temperature of deep lakes, used a thermometer protected against pressure and surrounded with non-conducting substances, cloth and wax, which allowed the instrument to be hauled up 1 000 ft. without changing the reading 0.1° Cent. The deep sea thermometers of Negretti and Zambra and of Cassela have very much facilitated the taking of bottom temperatures, but the thermophone as developed* and first used on the Boston Water-Works has revolutionized the methods of observing temperatures in the author's practice. This instrument allows the temperatures to be read at the surface by aid of the telephone. It depends upon the principle of the Wheatstone bridge. An electric circuit is formed through two small wires of different metals, which are enclosed in a metallic case sunk to any desired depth. The other two arms of the bridge are formed at the surface, the telephone taking the place of the galvanometer. This instrument is so accurate that its results can be depended upon to much less than 0.1° Fahr., and a series of temperatures throughout the vertical can be taken with an allowance of about a minute for each point observed.

As the old tables, already referred to, contain so many inaccuracies, it has not been thought worth while to print them in full in this paper, but the averages are given in Table No. 1. The surface temperatures are generally not far from right. The deeper the level, the greater the inaccuracy as a rule. For the bottom temperatures in Lake Cochituate the observer at times kept his bottle and thermometer at the bottom and pulled them up only for record. By studying this five-year series in connection with the thermophone tables herewith printed, the author has been able to form an accurate idea of the seasonal changes going on in large bodies of water.

Surface Temperatures.—By combining the surface temperatures taken at any particular spot for five years, a mean has been obtained. These means are so similar that they have all been combined in one diagram, which is believed to represent approximately the surface temperature of bodies of water of depths varying from 20 ft. to 80 ft. and under the same climatic conditions as those which prevail in the vicinity of Boston; but it must be borne in mind that five years is rather a short period

* By Messrs. H. E. Warren and G. C. Whipple.

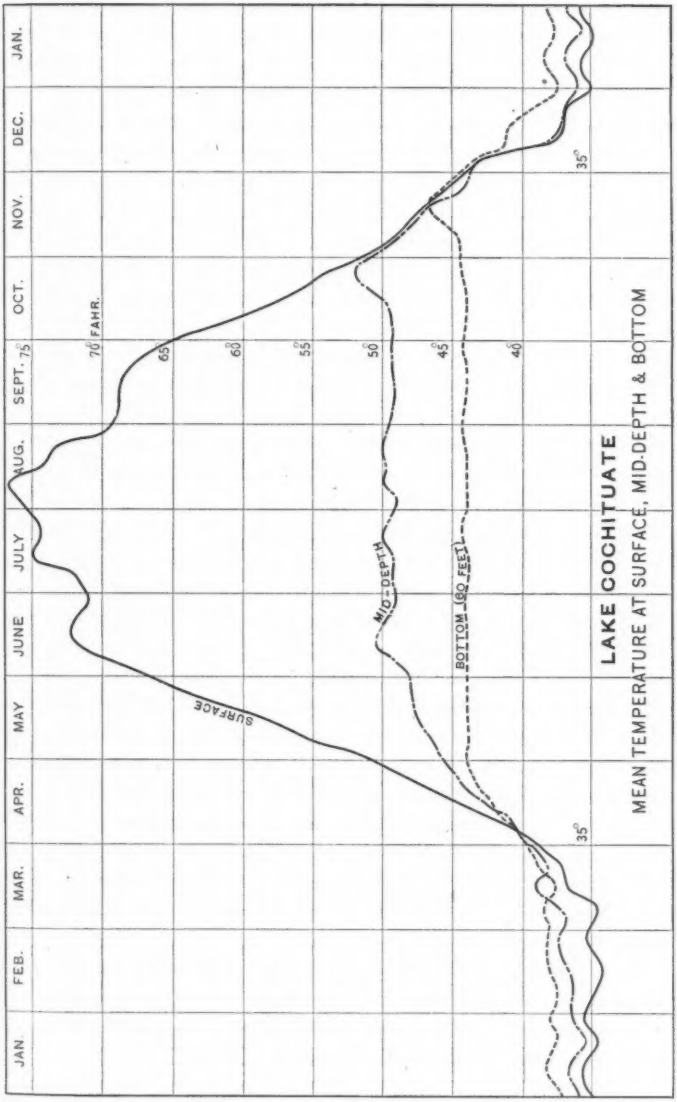
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
70° FAHR.
75°
65°
60°
55°
50°
45°
40°
35°
35°
SURFACE
MID-DEPTH
BOTTOM 160 FEET
LAKE COCHITUATE
MEAN TEMPERATURE AT SURFACE, MID-DEPTH & BOTTOM

FIG. 1.

from which to form a mean, and that some of the irregularities might be smoothed out and somewhat different values obtained by a longer term of observations. This diagram is not given here for the reason that it is quite similar to that given for Lake Cochituate in Fig. 1.

During the winter the water under the ice is sufficiently near the freezing point to fix it at 32° Fahr. from the latter part of December to the breaking up of the ice in the spring. The surface then begins to warm up at a uniform rate from 40° in the latter part of March or first of April, to 72° in the middle of June, making the mean temperature for April about 45°, and for May about 58°. In the middle of June there is a noticeable depression in the curve, which rises to but 73° on the first of July; in the Cochituate curve it actually falls to 71°. The temperature then rises sharply to 75° by the middle of July on both curves. The mean temperature for June is approximately 71°. In the middle of July there is another depression in both curves, and the temperature is nearly uniform (75°) during the remainder of the month, leaving the average temperature for July at about 74°. The curve rises slightly in the first week in August to 76.5°, which is the summit of the curve, and from this time the temperature falls rapidly to about 69° on September 1st. The mean temperature of August is, therefore, about the same as that for July. After the first of September there is a very interesting flattening of the curve until the middle of the month, when it is still at 69°. Then there is a drop to 65° on October 1st. The mean temperature for September is about 67.5°. Throughout October the curve is almost a straight line, reaching 50° by the mean curve and 51.5° by the Cochituate curve on November 1st. The mean for October is about 57°. The cooling goes on rather more slowly in November, reaching 40° on December 1st in the mean curve, and 44° on the Cochituate curve. The mean temperature for November may therefore be set down as somewhere in the neighborhood of 46°. By the middle of December the temperature reaches 37°, and after this time it drops quickly to the freezing point if in a shallow pond, and more slowly if in a deep one.

This heating of the surface of a body of fresh water during the larger part of the year gives rise to some interesting phenomena in connection with the subject of water temperatures and also with questions affecting a domestic water supply, as will be shown.

Bottom Temperatures.—If a pond is less than about 25 ft. in depth,

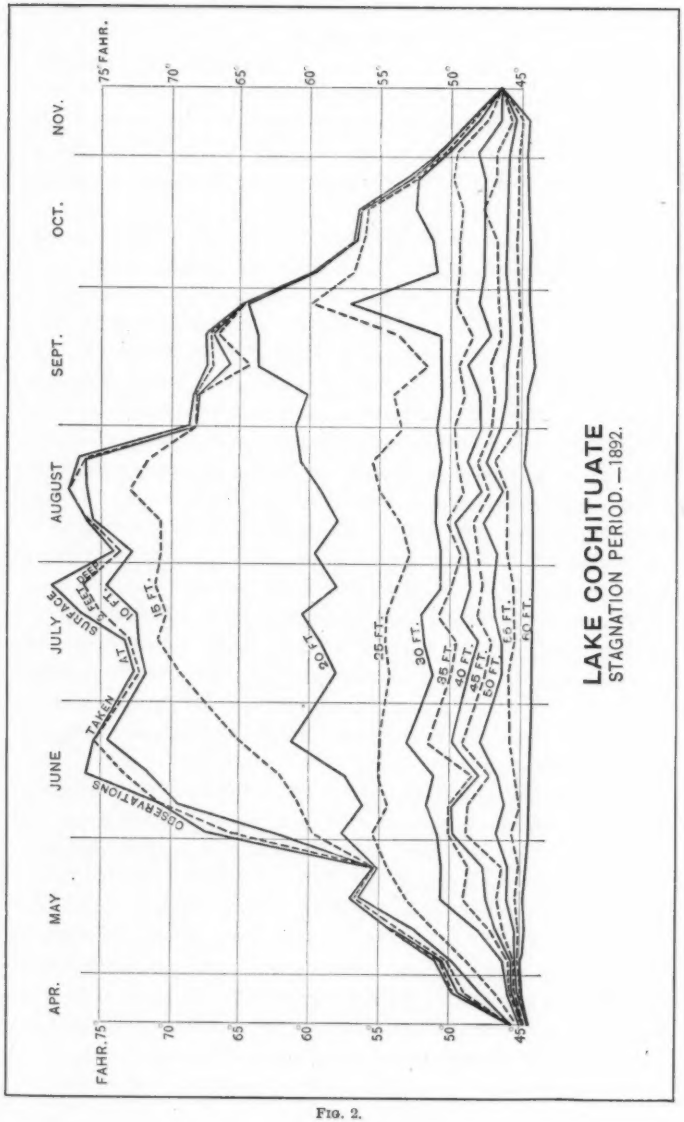
LAKE COCHITUATE
STAGNATION PERIOD.—1892.
APR.
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
FAHR. 75°
70°
65°
60°
55°
50°
45°
SURFACE
3 FEET
10 FT.
15 FT.
20 FT.
25 FT.
30 FT.
35 FT.
40 FT.
45 FT.
50 FT.
60 FT.
OBSERVATIONS TAKEN AT

FIG. 2.

the bottom temperature does not vary very much from that at the surface, although in the winter it may be 5 or 6° warmer, and in the middle of summer as many degrees cooler. These shallow ponds or lakes do not provide the interesting phenomena which are to be discussed, and but little more attention will be given to them. The winds in summer keep the water stirred up throughout, and there is little stagnation of the bottom layers, except, perhaps, for a short time in the winter.

With deeper lakes, however, a very different state of things prevails. Starting with the freezing over of a deep lake about January 1st, the bottom temperatures, as they exist on the Boston Water-Works, will be now traced. The point of maximum density of fresh water is 39.2°. When Lake Cochituate freezes, the temperature of the bottom is generally near this point in the deep portions, although in a lake of the same depth, say 70 ft., the temperature may be much below this if the weather is severe and the winds high before the ice forms. The several strata lie in their order of density, decreasing gradually until within a few feet of the surface, when they suddenly fall to the freezing point adjoining the ice. The form of this curve is quite persistent in all lakes, although there are many variations from it in places where there are currents or other local modifying causes, as may be seen by an inspection of the tables and diagrams in this paper. In a general way the whole body of water remains unchanged after the ice forms until it is broken up in the spring, but there are some interesting details connected with certain changes going on even under the ice which will be discussed later. It is desirable first to obtain a general comprehension of the subject.

As the surface warms about April 1st to the same temperature as the bottom, the whole body of water is in unstable equilibrium, and circulation takes place from top to bottom under the action of the winds and currents. Finally, by the first of May, when the surface temperature has risen and gained about 5° upon the bottom, the difference in density seems to be sufficient to prevent any further warming of the bottom; and while the surface keeps on warming, the bottom remains at almost exactly the same temperature throughout the long period of stagnation until the middle of November, covering a period of nearly seven months, and varying during that time, so far as can now be determined, only a few tenths of a degree. Of course, this

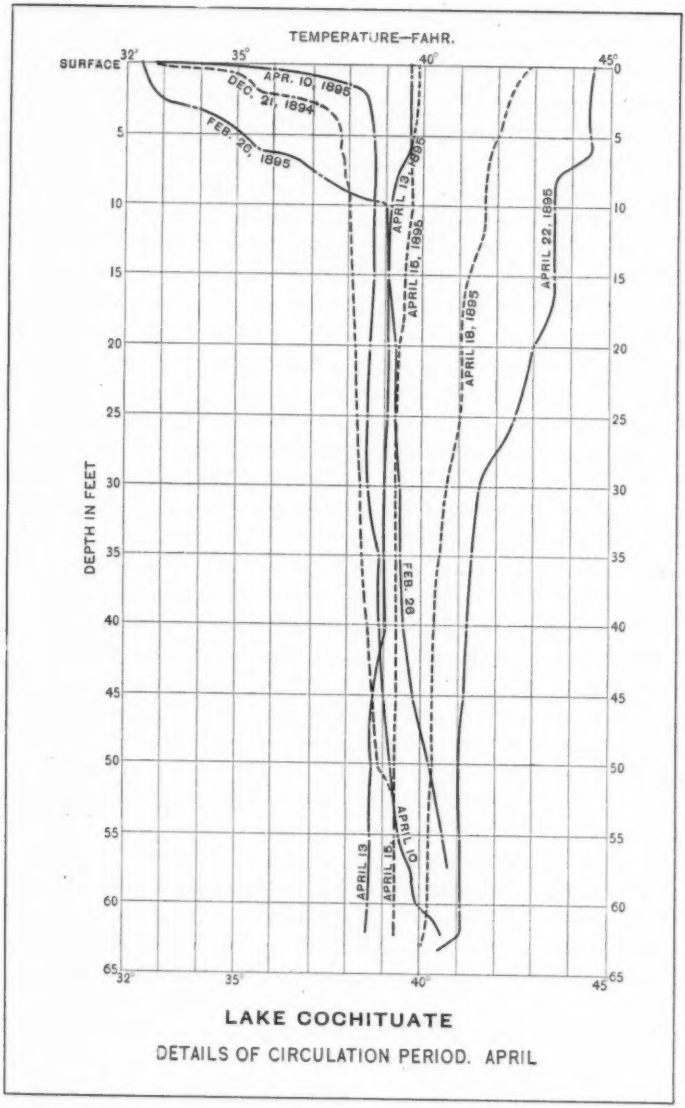
TEMPERATURE—FAHR.
SURFACE
32°
35°
40°
45°
APR. 10, 1895
DEC. 21, 1894
FEB. 20, 1895
APRIL 13, 1895
APRIL 16, 1895
APRIL 18, 1895
APRIL 22, 1895
FEB. 28
APRIL 13
APRIL 15
APRIL 10
DEPTH IN FEET
0
5
10
15
20
25
30
35
40
45
50
55
60
65
LAKE COCHITUATE
DETAILS OF CIRCULATION PERIOD. APRIL

FIG. 3.

means that the winds do not penetrate to this depth; neither are there convectional currents to change the temperature, and, as water is a poor conductor of heat, the sun's rays, however hot, are practically powerless at a depth of 65 ft. in Lake Cochituate. It will be noticed in Fig. 1 that the bottom temperature begins to rise in the middle of March from about the point of maximum density, but that it falls slightly before rising. This was thought to be an error of observation, but careful investigation with the thermophone during the present year has shown this not to be the case. The water before heating at the bottom first cools slightly. From the middle of March to the first of May the temperature rises to 44°, and the early part of April may be called the first period of circulation, the water for a short time remaining at the same temperature from top to bottom. From May 1st to November 1st the bottom temperature remains at 44°, and rises between November 1st and November 15th about 2° or 3° to meet the surface temperature, and then the whole mass of water falls at nearly the same rate in a second great period of circulation until freezing begins, which separates the surface and bottom, the latter remaining somewhat nearer the point of maximum density.

Turning for a moment to the other reservoirs, their bottom temperatures will be found to follow those of Lake Cochituate, but with this difference. As Basins 2, 3 and 4 are shallower, the winds are able to keep up more of a circulation, with the final result of less difference of temperature between the top and bottom layers, so that in the case of Basin 4, in a depth of about 50 ft. of water, the permanent summer temperature of the bottom is not reached until about a month later than in Lake Cochituate, and it is then about 9° higher, or 53°. Basins 2 and 3 are not deep enough for their bottoms to remain stagnant, but their temperatures are proportional to their depths.

Summer Stagnation Period.—For four years, 1891–94, the temperatures in Lake Cochituate have been taken weekly for every 5 ft. in depth during the summer stagnation period, April to November. These results are found in Table No. 2, and those for 1892 have been plotted in Fig. 2. The diagram enables the effects of the wind on the different layers to be studied. It will be noticed that throughout the period the temperature at a depth of 10 ft. is about the same as at the surface, showing that the winds keep the water stirred up thoroughly to this depth, but below 15 ft. the effect of the wind is

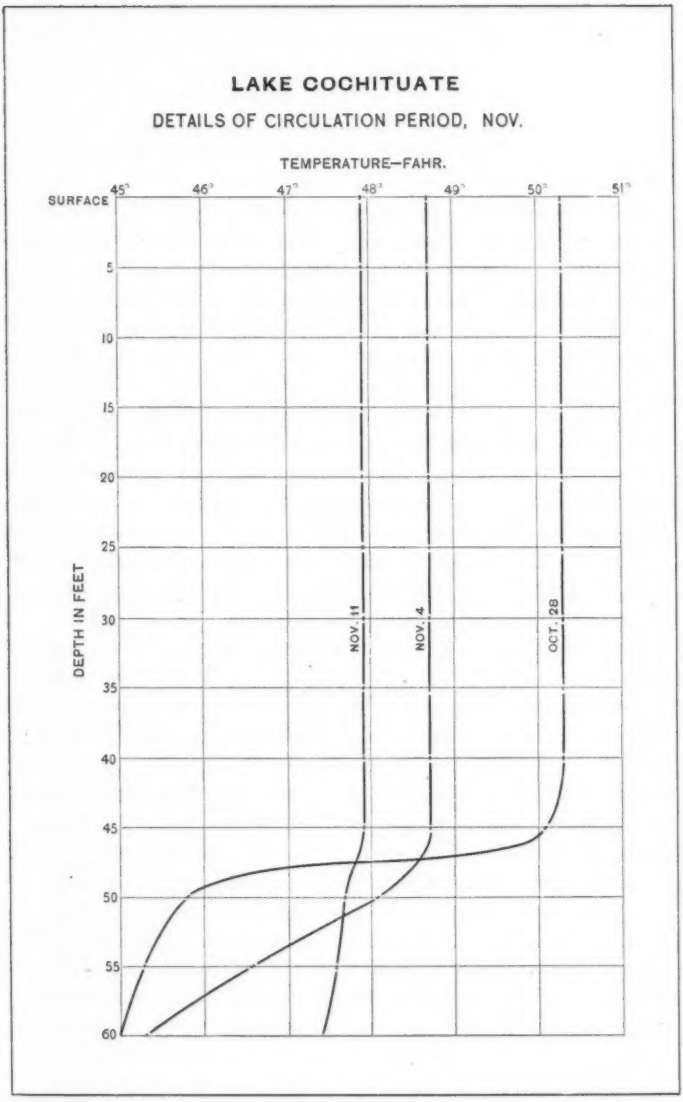
LAKE COCHITUATE
DETAILS OF CIRCULATION PERIOD, NOV.
TEMPERATURE—FAHR.
SURFACE
45°
46°
47°
48°
49°
50°
51°
5
10
15
20
25
30
35
40
45
50
55
60
DEPTH IN FEET
NOV. 11
NOV. 4
OCT. 28

FIG. 4.

small. It must be remembered, however, that a season of the year is now under consideration when the difference in density is greatest between the top and bottom, and it will be found later that when this density is less, the effect of the wind reaches very much lower. As the layers are followed to the bottom, it will be noticed that they warm up less and less, until near the bottom the temperature lines are parallel.

Effects of Stagnation.—Some of the effects of stagnation are very remarkable. They have been fully set forth by the author in the Boston Water Board reports, and it will be unnecessary to repeat them here. It may be said, however, that in a lake with any considerable amount of organic matter in it and also in deep artificial storage reservoirs, where the surface has not been stripped, the lower layers, which are quiescent during the great stagnation period, gradually collect all the organic matter from the upper layers, and decay goes on until the oxygen is used up. The water becomes darker and darker, until by October it is very yellow, and generally has a disagreeable smell. Of course, when the great overturning comes, in November, all this bad water is brought to the surface, and the infusoria and diatoms begin to grow in enormous numbers, because the organic matter and oxygen are brought together and provide food for organic life. The same phenomenon takes place in the spring period of circulation, although on a smaller scale.

It is astonishing to a novice to take him out in a boat when the surface temperature is near 80°, and sink a bottle and bring up water icy cold from the bottom. In this connection it is interesting to consider that if Lake Cochituate were 1 000 ft. deep instead of 65 ft., this water from the bottom would probably be only 4° colder than it is. It is also possible toward the end of the stagnation period, with a little knowledge of a lake, to draw water of any desired quality according to the layers selected.

At the surface the water may be, and generally is, free from color and of excellent quality, while that at the bottom is in the worst condition. In a lake free from organic matter or in one which is so large that the organic matter brought in by the feeders is completely oxidized, or in a large artificial storage reservoir thoroughly constructed from a sanitary point of view, the phenomenon which has been described is almost entirely lacking, but it is somewhat rare to find a lake of such great purity that the water is as good at the bottom in

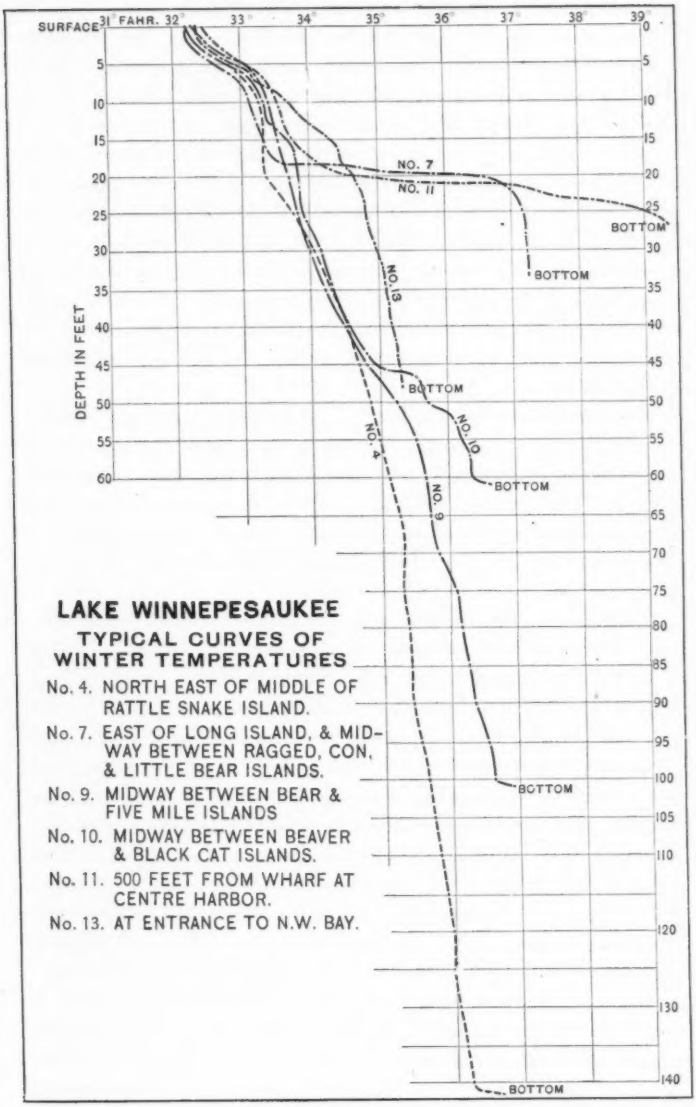
SURFACE
31° FAHR. 32°
33°
34°
35°
36°
37°
38°
39°
DEPTH IN FEET
NO. 7
NO. 11
NO. 13
NO. 4
NO. 9
NO. 10
BOTTOM
BOTTOM
BOTTOM
BOTTOM
BOTTOM
LAKE WINNEPESAUKEE
TYPICAL CURVES OF WINTER TEMPERATURES
No. 4. NORTH EAST OF MIDDLE OF RATTLE SNAKE ISLAND.
No. 7. EAST OF LONG ISLAND, & MIDWAY BETWEEN RAGGED, CON, & LITTLE BEAR ISLANDS.
No. 9. MIDWAY BETWEEN BEAR & FIVE MILE ISLANDS
No. 10. MIDWAY BETWEEN BEAVER & BLACK CAT ISLANDS.
No. 11. 500 FEET FROM WHARF AT CENTRE HARBOR.
No. 13. AT ENTRANCE TO N.W. BAY.

FIG. 5.

the latter part of summer as it is at the surface. Experience in these matters will enable a fair opinion to be formed of the quality of a water without even a microscopical or chemical analysis, but this does not mean that a great many analyses are not necessary before one can judge of the quality of any water with scientific confidence.

A knowledge of the facts here narrated should lead to letting out or wasting the bottom water before November 1, when the construction of deep reservoirs will allow. In the case of deep artificial reservoirs containing organic matter, where the dam is at the lowest part of the valley, this is easily accomplished and should result in preventing the distribution of the impurities. A person living near a deep lake might arrange to draw good water from the surface through a long coil placed at the bottom and in this way secure good and very cold water all summer.

Circulation Periods.—The spring and autumn circulation periods already referred to, when the water is at the same temperature from top to bottom in the lakes under discussion, contain some interesting changes. In Table No. 3 and Fig. 3 will be found some accurate observations taken in Lake Cochituate under the ice from December 21st, 1894, to the breaking up of the ice on April 10th, 1895, and for several days after this last-named date.

It will be seen that on December 21st after the ice had formed, the temperature at the surface under the ice was at 32° and rose rapidly in the first 5 ft. to 37.8° and then very regularly to 39.2° at the bottom. On February 26th the temperature of the bottom had risen to 40.7° with some cooling effects in the upper layers, due probably to the emptying of a large mass of cold water into the lake from another source of supply, the Sudbury River. The heating of the lower layers may have been due to springs, the heat of the earth, to chemical action or to some cause which the author does not now comprehend. From February 26th to March 29th, there was very little change in the lower 40 ft. of water. On April 10th, when the ice was broken up into floating cakes and there was a very high wind, the surface was found at 33°. At a depth of 2 ft., it was at 38.4° ; at 6 ft., 38.7° ; and by tracing the curve below this point it will be seen that the lower 40 ft. of water had cooled about half a degree, although the bottom still remained at the same temperature as in February and March. On April 13th, the bottom had cooled to 38.6°, while the surface had warmed to

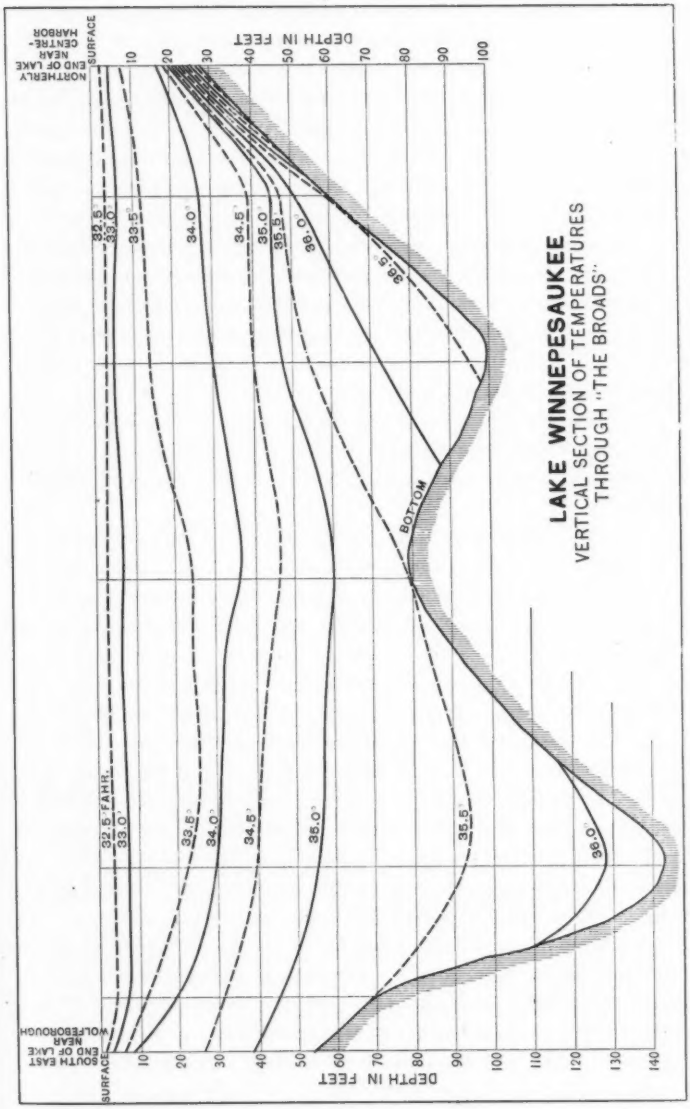
LAKE WINNEPESAUKEE
VERTICAL SECTION OF TEMPERATURES
THROUGH "THE BROADS".
NORTHERLY END OF LAKE NEAR CENTRE-HARBOR
SOUTH EAST END OF LAKE NEAR WOLFEBOROUGH
SURFACE
BOTTOM
DEPTH IN FEET
32.5 FAHR.
33.0°
33.5°
34.0°
34.5°
35.0°
35.5°
36.0°
38.5°

Fig. 6.

39.8°, and at a few feet below the surface and for a long distance toward the bottom, the water was very nearly at the point of maximum density. In other words, while the surface was warming up, the bottom was getting perceptibly colder, and it may be thus considered as proved that when the mass of the water is in this condition of unstable equilibrium, the wind and currents change the temperature rapidly from the surface to the bottom. These changes cannot be due to conduction, for it was shown that for half the year, while there may be 30° difference at times between the surface and the bottom, there is no appreciable heating of the bottom layers by conduction. From the observations taken after April 13th, it will be noticed that the heating of the whole mass of the water goes on until about the first of May, shown in Fig. 2, when there is a separation of the surface and bottom temperatures, as already described.

An examination of the tables shows that in the cooling of the lake in the autumn the reverse process takes place, and there is a warming of the bottom layers before they begin to cool. This is shown graphically on Fig. 4.

Lake Winnepesaukee.—Table No. 5 and Fig. 5 contain some observations taken under the direction of the author in Lake Winnepesaukee. This lake is situated to the north of Boston and contains 70 sq. miles of water surface. It is 150 ft. deep in the deepest portion, so far as ascertained. As the water of Lake Cochituate at 65 ft. depth was found at about 44° in summer, and the other reservoirs were found proportionately warmer as they decrease in depth, it was expected that Lake Winnepesaukee would be found colder at 150 ft. than Lake Cochituate at 65 ft., but to the surprise of the author, it was found to be about 10° warmer (see Table No. 5). As the ice breaks up later in the season and the period of circulation takes place in warmer weather and is perhaps more prolonged on account of the mass of water to be affected, it is probable that by the time stagnation of the lower layers begins, the bottom has reached 54°.

The winter temperatures taken under the ice are very interesting, showing that the mass of water cools down to a lower point than does Lake Cochituate. This the author believes is accomplished by the winds and currents before the surface freezes over. The bottom temperatures, 36.65° at 100 ft. and 36.25° at 141 ft., are much below maximum density. At points where there are swift currents and local

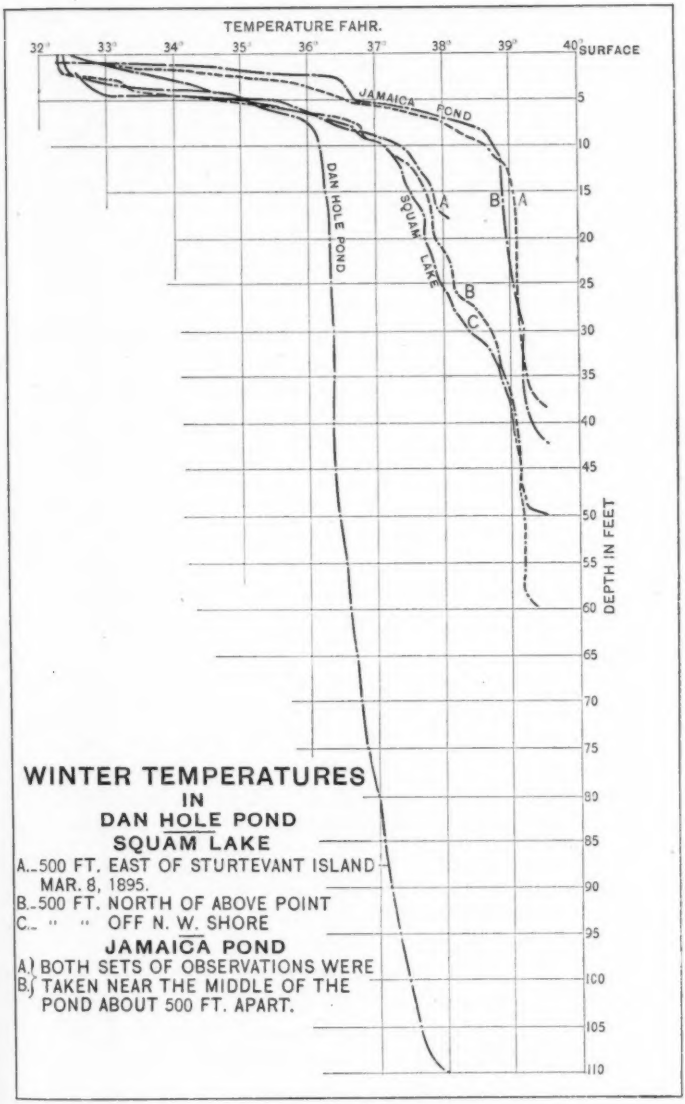
TEMPERATURE FAHR.
32°
33°
34°
35°
36°
37°
38°
39°
40°
SURFACE
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
DEPTH IN FEET
JAMAICA POND
DAN HOLE POND
SQUAM LAKE
A
B
A
B
C
WINTER TEMPERATURES
IN
DAN HOLE POND
SQUAM LAKE
A.-500 FT. EAST OF STURTEVANT ISLAND
MAR. 8, 1895.
B.-500 FT. NORTH OF ABOVE POINT
C.- " " OFF N. W. SHORE
JAMAICA POND
A, B, BOTH SETS OF OBSERVATIONS WERE
TAKEN NEAR THE MIDDLE OF THE
POND ABOUT 500 FT. APART.

FIG. 7.

reasons for a different result, the curves change very materially in form, but these are fully shown in the tables and diagrams and require no farther explanation. The inclination of the isotherms in the cross-section of the lake is shown in Fig. 6.

Squam Lake, just north of Lake Winnepesaukee, was found to be at the point of maximum density at the bottom in 59 ft. of water, and at another point, 17 ft. deep, the temperature at the bottom was 37.95 degrees.

Dan Hole Pond, in the same vicinity, and one of the so-called "ponds without a bottom," was found to be 109 ft. deep and to have a temperature of 37.85° at the bottom.

All of the above temperatures, taken under the ice, follow in their curves the same form as in all frozen lakes (see Table No. 6 and Fig. 7).

Lake Superior.—The only observations of this lake that the author has been able to secure were taken in 1871 by the United States Lake Survey, and are given in Table No. 7. The surface and bottom temperatures in August only are given, and show the bottom to be at about 38.8° in 158 fathoms. The surface temperature was from 50 to 53°. The water in this lake is noted for being very cold. As the surface never freezes over it would not be difficult to construct a diagram of the probable ranges in temperature throughout the year, very much as the anatomist constructs a complete skeleton from one or two bones.

Lake Tahoe.—Latitude 39° north, and longitude 120° west. Professor Le Conte, in August, 1873, found the temperature in this lake, at a depth of 1 506 ft., to be 39.2° Fahr.; at 772 ft., 41.0°, and 67.0° at the surface.

F. P. Stearns, M. Am. Soc. C. E., has published in the Report of the Massachusetts State Board of Health, 1890, entitled, "Examination of Water Supplies," an excellent article on the temperature of water. Mr. Stearns' observations on the Upper Mystic Lake, Medford; Jamaica Pond, Boston; and Wenham Lake, Wenham, have been incorporated in Table No. 8.

Professor William R. Nichols read a paper in 1880, before the Boston Society of Natural History, "On the Temperature of Fresh Water Lakes and Ponds," which contains a valuable bibliography on the subject, and is characterized by the deep scientific knowledge possessed by him. Professor Nichols, however, leaned toward the conduction theory.

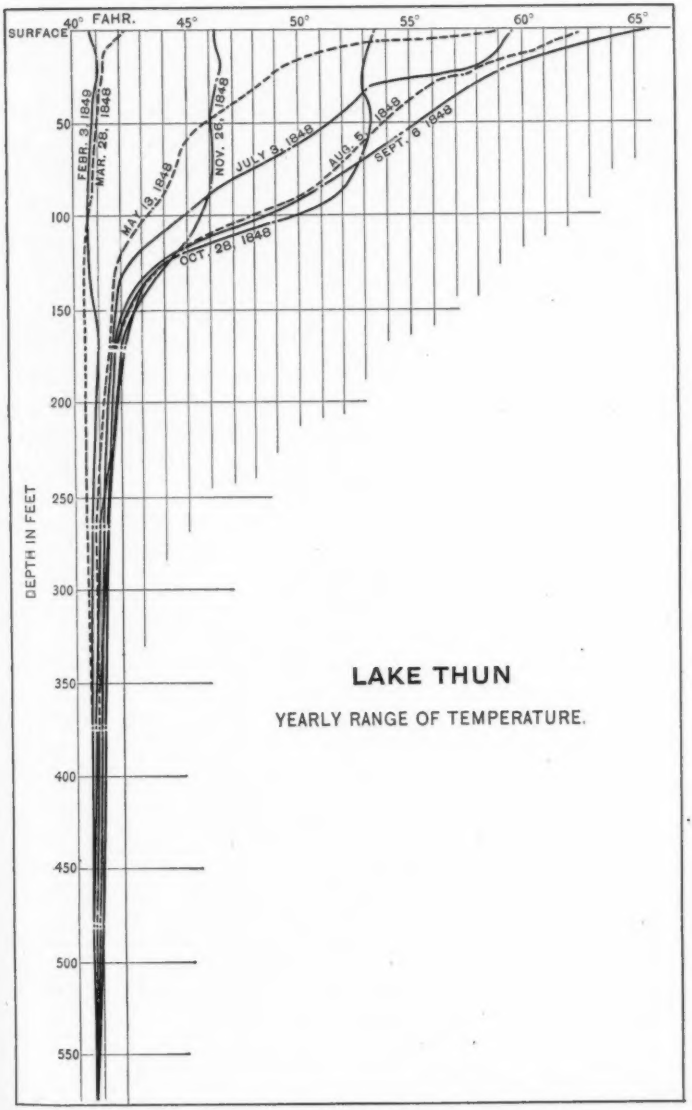
SURFACE
40° FAHR.
45°
50°
55°
60°
65°
50
100
150
200
250
300
350
400
450
500
550
DEPTH IN FEET
FEBR. 3, 1849
MAR. 28, 1849
MAY 13, 1849
NOV. 26, 1848
JULY 3, 1848
AUG. 5, 1848
SEPT. 6 1848
OCT. 28, 1848
LAKE THUN
YEARLY RANGE OF TEMPERATURE.

FIG. 8.

Foreign Lakes.—Extended series of observations on the temperatures of lakes are very rare; in fact, the number of observers who have done valuable work in this direction may be counted on the fingers of one hand. The work of M. H. B. de Saussure, already referred to, is contained in Table No. 9. It will be seen that there are no intermediate temperatures given between the surface and bottom. The results are very close to those obtained by subsequent observers who had the advantage of better instruments, but the observations are now interesting principally from the historical point of view.

One of the most valuable series was taken by MM. C. de Fischer-Ooster and C. Brunner in Lake Thun in 1848–49 (see Table No. 10 and Fig. 8). It was probably the first to give an idea of the seasonal changes going on in a large body of water, and, although taken like M. de Saussure's, without the advantage of deep-sea thermometers, it bears every stamp of accuracy. A number of protected thermometers were fastened to a line and allowed to remain all night, when they were drawn up rapidly and read. The series consists of nine soundings taken in different months of the year and extending to a depth of 550 Swiss feet. They show a variation at the bottom during this time of only about 0.2° Fahr., the mean being 40.7°, slightly above the point of maximum density.

The authors refrained from speculation in their admirable paper,* but they pointed out clearly by means of diagrams the diminution of temperature throughout the mass in the winter and the heating of the lower strata long after the surface had begun to cool off. It is shown that the maximum temperature at depths of 10 to 80 ft. occurs in September; at 80 to 120 ft. in October, and at 120 to 350 ft. in November, while below this point the changes are very slight.

The following extract is from the paper:

"In glancing over this table it is surprising to note the slowness with which the action of the summer sun penetrates into the interior of the water. Although the object of this memoir is to give only such facts as were observed, I cannot but draw attention to these results, which afford information concerning the conduction of heat by water. In closing, I must note that the level of uniform temperatures commences very nearly at a depth of 150 m., and that this temperature varies between 4.8° and 4.9° Cent."

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* Published in the *Mémoires* of the Société de Physique et d'Histoire Naturel, Geneva; Vol. XII.

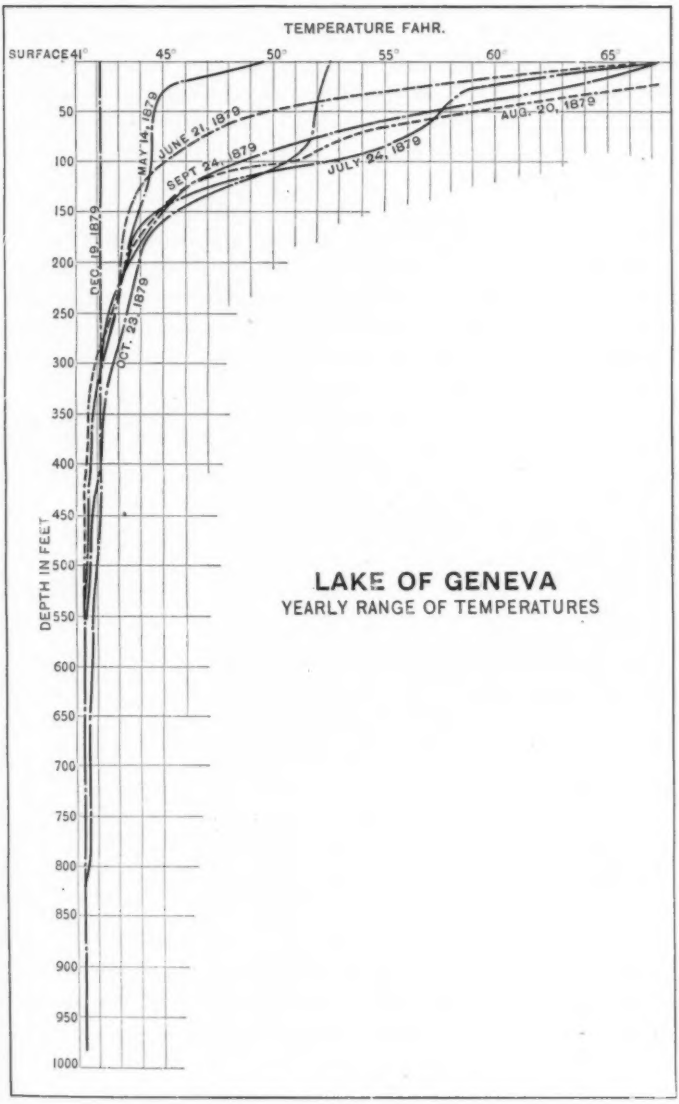
TEMPERATURE FAHR.
SURFACE
41°
45°
50°
55°
60°
65°
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
DEPTH IN FEET
MAY 14, 1879
JUNE 21, 1879
SEPT 24, 1879
JULY 22, 1879
AUG. 20, 1879
DEC. 18, 1879
OCT. 23, 1879
LAKE OF GENEVA
YEARLY RANGE OF TEMPERATURES

FIG. 9

The above facts are apparently a strong argument in favor of the theory of conduction, but if the heating of the lower layers in Lake Cochituate occurs from the mingling which goes on between the layers as they approach each other in temperature, as the author has endeavored to show, there is every reason for supposing that the same action goes on in Lake Thun, and that conduction has nothing to do with the question.

Lake of Geneva.—M. F. A. Forel has been one of the most voluminous writers on the temperature of lakes. His observations embodied in Table No. 11 and Fig. 9 have been confined principally to the Lake of Geneva, which has a depth of about 1 000 ft. While not as complete as the Fischer-Ooster observations, they are extremely interesting, confirming in many respects the work of the former and showing the similarity of the results in the two lakes.

He has shown,* from some soundings taken in 1885, that the isotherms of the Lake of Geneva are not horizontal, but inclined, being considerably warmer at a depth of 60 m. at the Chillon end of the "Grand-Lac" than at the same depth at the entrance to the "Petit-Lac." He ascribes this action to the sediment brought into the lake by the Rhone, which he says gives a greater density to the water than that due to its temperature alone, and so it sinks deeper and warms the deep layers of the lake at one end.

In another article † Forel has given the following results of several years of observations:

	Centigrade.	Fahrenheit.
1879	5.2°	41.4°
1880	4.6°	40.3°
1881	4.8°	40.6°
1883	5.0°	41.0°
1884	5.4°	41.7°
1885	5.6°	42.1°
1886	5.3°	41.5°

He admits that the cooling of a lake in the winter is easily explained on the theory of thermic conduction, but that the heating process, which goes down to the most profound depths, is not so easily

* See *Comptes Rendus*, Vol. CII, 1886, p. 712.
† See *Comptes Rendus*, Vol. CIII, p. 47.

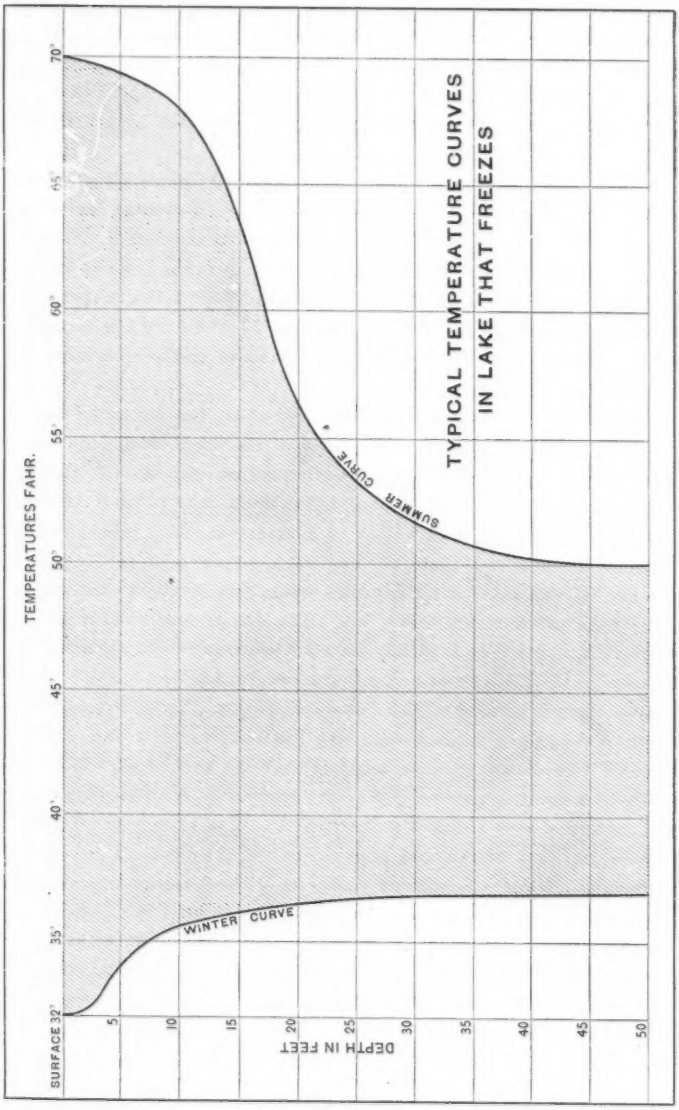
TYPICAL TEMPERATURE CURVES
IN LAKE THAT FREEZES
TEMPERATURES FAHR.
SURFACE 32°
35°
40°
45°
50°
55°
60°
65°
70°
SUMMER CURVE
WINTER CURVE
DEPTH IN FEET
5
10
15
20
25
30
35
40
45
50

FIG. 10.

accounted for by the same theory. He cites a notable instance in his experience when, after a very severe period of high winds and gales in April, he found the temperature had penetrated to extraordinary depths, while the surface had grown cooler. He concludes that the heating is due to a mechanical mixture under the action of the winds.

Table No. 12 contains some interesting observations cited by M. Forel.* Three of the observations were taken in the winter, under the ice, and their close agreement with the results of the author, obtained on the Boston Water-Works and in Lake Winnepesaukee, can be seen at a glance. M. Forel shows that in the Lake of Geneva the temperature at the bottom during the severe winter of 1879–80 did not fall below 5° Cent., and that it is doubtful whether the water in the open lake has ever reached 4° Cent. (39.2° Fahr.).

Conclusions.—It remains now, in view of all the foregoing facts, brought together from different parts of the world, to discuss some of the points connected with the temperature of lakes not already made clear; of course, the discussion can apply only to lakes situated in a climate somewhat like that of Boston. In deep lakes covered with ice in the winter, there are two lines or curves of profile which confine the variations of temperature within certain limits—the winter curve and the summer curve; and these curves nearly meet at the bottom, if it is a very deep lake, and are separated by a considerable interval as the lakes become more shallow. A common shape for the winter curve is to start with 32° at the surface, and increase rapidly to 36° at a depth of 5 ft., and then very gradually towards 39.2° at the bottom. The summer curve may begin at the surface with 75°, and then, by a reverse curve, a type easily recognized from the diagrams, reduce to 45–50° at the bottom (see Fig. 10). The variations from this profile are pronounced, but easily explained by situation, extent of surface and depth. A very remarkable variation from the winter curve is seen in the several sets of observations taken in Lake Cochituate and other lakes, under the ice, which give bottom temperatures higher than 40° (see Fig. 11). As the temperature under the ice is necessarily near 32°, it is evident that the point of maximum density in these cases is some distance above the bottom. Crystal Lake, shown in Fig. 11 and embodied in Table No. 6, is a small body of clear water fed

* See *Comptes Rendus*, Vol. XC, 1880, p. 322.

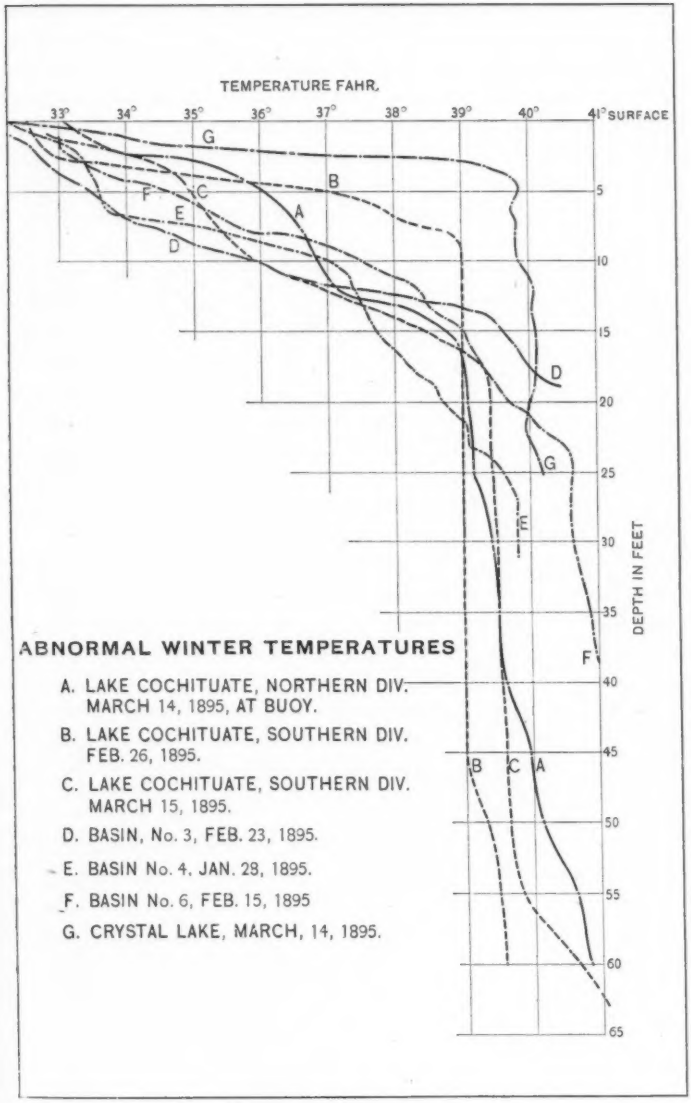
TEMPERATURE FAHR.
33°
34°
35°
36°
37°
38°
39°
40°
41°
SURFACE
5
10
15
20
25
30
35
40
45
50
55
60
65
DEPTH IN FEET
ABNORMAL WINTER TEMPERATURES
A. LAKE COCHITUATE, NORTHERN DIV. MARCH 14, 1895, AT BUOY.
B. LAKE COCHITUATE, SOUTHERN DIV. FEB. 26, 1895.
C. LAKE COCHITUATE, SOUTHERN DIV. MARCH 15, 1895.
D. BASIN, No. 3, FEB. 23, 1895.
E. BASIN No. 4. JAN. 28, 1895.
F. BASIN No. 6, FEB. 15, 1895
G. CRYSTAL LAKE, MARCH, 14, 1895.

FIG. 11.

entirely by springs. In this case it is possible that the ground-water entering the pond gradually raised the temperature beyond the point of maximum density, and that this heating effect continued upward nearly to the ice line. This is the most exaggerated case that the author has found. The corroborative evidence of all these curves is beyond question. A study of the tables shows that this condition of unstable equilibrium may continue for a long time, but it is certainly very curious, and, as far as the author knows, has never been noticed before.

In a lake of the first order, like that of Geneva, the winds produce a mechanical mixture of the layers to a considerable depth below the surface, even in the summer, say to 150 ft. in depth, as is evident from the tables. The return currents, being much warmer and lighter than the lower layers, must pass over them. The smaller the lake, the less these mechanical effects are felt. In Lake Cochituate, for instance, they are hardly found 20 ft. below the surface; but that this extensive heating to considerable depths in large lakes is not due to conduction seems to be proved by the fact that at 65 ft. depth conduction has no effect in seven months' time in altering the bottom temperatures of Lake Cochituate. When the water is of nearly the same temperature throughout, the return currents may pass to the bottom and circulation may occur to great depths. This uniformity of temperature in ordinary lakes takes place at two points in the yearly profile, and at these times the wind effects are felt to great depths. In a very large lake which does not freeze, this period occurs during the winter only, but these changes are probably prolonged, and, at any rate, are sufficient to prevent periods of stagnation extending from one year to another.

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TABLE No. 1.—Weekly Mean Temperatures (Fahr.) for Five Years, 1890–94, Boston Water-Works.

Date.	Lake Cochituate.			Basin 2.		Basin 3		Basin 4.		Chestnut Hill Reservoir.			Brookline Reservoir.	Boston Tap Water.	
	Surface.	Mid-depth.	Bottom	Surface.	Bottom.	Surface.	Bottom.	Surface.	Bottom.	Surface.	Bottom.	Gate-House.	Gate-House.	City.* "Common."	Mattapan.†
Jan. 1....	35.2	36.2	37.7	35.4	36.5	35.0	37.3	35.0	37.1	36.8	37.9	36.8	37.0	40.7	42.1
8....	35.8	36.9	38.4	33.3	35.4	33.7	35.3	34.1	36.3	35.6	36.4	35 5	36.7	39.0	41.2
15....	34.6	35.6	37.5	33.2	34.7	33.3	36.0	34.1	36.9	35.2	35.5	35.7	36.6	39.3	40.7
22....	35.5	36.5	38.0	33.7	35 4	33.6	36.1	34.6	36.9	34.0	36.5	35.7	36.4	38.2	39.3
29....	35.6	36.5	37.6	33.7	35.2	33.9	36.7	34.5	37.3	34.4	35.7	36.6	36.5	38.4	39.1
Feb. 5....	34.4	36.4	37.8	33.9	36.1	33.8	37.1	35.0	37.2	35.3	35.9	36.2	36.6	37.4	38.5
12....	34.6	37 0	38.1	33.4	36.0	33.9	37.0	34.0	37.6	34.1	36 1	36.1	36.4	38 1	38.5
19....	35.6	37.5	38.3	34.0	35.6	33.3	37.2	34.1	38.2	33.2	35.7	35.7	36.4	37.3	37.5
26....	34 9	36 8	38.1	33.4	35.7	33.4	35.9	33.8	37.3	35.3	35.9	35.1	36.2	37.5	38.0
Mar. 5....	34.7	37.4	38.5	33.8	36.0	33.5	37.1	34 4	37.9	32.9	35 0	35.9	36.1	38.1	38.0
12	36.7	38.9	37.4	35.0	36.4	34.3	36.6	35.3	38.4	38.5	38.5	37.0	36.8	38.8	38.5
19....	37.0	38.2	38.6	37.0	38.1	36.5	38.3	38.1	39.7	40 2	40.6	37.7	38.1	39.5	38.8
26....	38.2	38.7	39.0	39.0	39.8	37.7	39.3	40.4	40.3	40.6	40.9	39.2	39.6	40.2	38.5
Apr. 2....	40.0	40 1	40.1	43.4	43.2	41.4	42.6	41.6	40.8	42.4	42.5	42 6	42.5	41.5	41.3
9....	42.2	41.2	41.7	45 9	45.3	44.9	44.9	44.1	43.6	44.6	44.8	45.5	43.9	44.5	41.4
16....	46.3	43.6	43.3	49.4	48.9	48.6	47.6	47.0	44.1	47.7	46.4	47.0	46.4	46.1	42.8
23....	49 0	44.9	43.8	52.4	51.9	50.7	50.5	50.8	47.5	50.7	48.8	50.0	49.8	50.4	45.0
30....	51.8	45.9	44.0	56.3	55.3	54.9	54.1	52.9	48.7	54.2	51.6	53.1	53 0	51.2	46.0
May 7....	55.9	46.5	43.8	57.8	57.0	56.7	54.7	56.0	50.0	56.7	54.2	55.7	54.4	54.3	48.6
14....	58.2	47.5	44.1	61.6	59 7	60.1	57.7	59.4	50.3	61.2	55.1	58.0	57.7	56.4	50.0
21....	61.6	47.8	44.0	62.3	60.1	60.7	58.6	60.9	50.4	59.9	57.2	60.0	58.5	56.9	50.1
28	64.8	48.0	44.2	65.7	62.2	63.9	60.4	65.8	53.1	64 3	58.1	61.7	60.8	61.0	52.9
June 5...	67 7	48.4	44.2	68.1	63.1	68.6	61.4	68.3	52.4	66.9	59.0	64.5	64.0	62.8	53.7
12	71.6	50.4	44.2	73.7	64.7	72.6	63.0	70.5	52.4	70.0	59.1	65,1	66.0	66.2	56.9

12 ...	71.6	50.4	44.2	73.7	64.7	72.6	63.0	70.5	52.4	70.0	59.1	65.1	66.0	66.2	56.9
19....	72.4	49.7	44.2	73.0	67.5	71.8	64.2	73.0	52.3	72.4	60.0	67.5	67.6	68.1	58.5
26....	71.2	49.1	44.3	72.5	68.0	70.9	62.7	71.2	52.3	71.2	58.2	68.6	69.6	68.5	59.8
July 3....	71.8	49.4	44.1	75.0	69.8	73.7	65.5	73.6	52.1	74.6	58.5	70.8	70.0	69.7	60.2
10....	75.1	49.3	43.9	76.3	71.0	75.1	66.2	75.9	52.9	75.7	59.3	71.5	71.7	71.1	61.1
17....	74.7	49.8	44.3	76.0	72.4	75.2	66 3	75.5	53.1	75.3	57.6	72 2	74.2	73.1	63.2
24....	74.9	49.7	44.4	75.8	71.7	75.0	66.9	76.0	52.9	75.3	60.4	73.1	74.1	73.6	64.0
31...	75.9	48.9	44.0	77.7	74.5	76.7	68.2	76.4	52.6	76.2	61.2	74.8	73.5	72.7	63.9
Aug. 7....	76 9	49.9	44.1	75.9	73.3	75.4	67.6	75.0	53.1	75.5	62 2	74.4	73.6	73.1	64.7
14....	74.5	49.8	44.0	73.6	72.3	73.2	67.2	73.9	52.5	74.8	63.1	73.8	74.4	73.2	64.7
21....	73.7	49.9	44.0	73.1	71.8	72 6	67.5	73.1	52.8	74.1	61.7	72.9	72.7	72.4	65.0
28....	69.8	49.6	44.5	71.3	70 1	70.8	67.9	70.8	52.5	69.9	62.3	71.7	70.7	70.4	64.2
Sept. 4....	68.9	49.3	44.3	68.6	67.4	68.7	67.1	68.1	54.1	69.7	63.6	69.4	69.1	68.7	63.1
11...	68.8	49.0	44.1	68.7	67.7	69.4	67.6	68.8	53.3	69.9	64.6	68 4	68.4	68.9	62.9
18....	68.3	49.3	44.1	68.2	67.2	67.8	66.5	66.8	57.1	68.6	63.9	67.9	67.5	67.1	62.2
25....	66.5	49.2	44.1	66.4	65.6	66.6	65 2	65.5	58 4	66.2	63.9	67.1	66.8	65.8	61.9
Oct. 2...	62.5	49 2	44.4	60.7	60.3	61.7	61.0	60.4	55.6	63.4	61.8	62.5	62.9	62.9	60.6
9...	58.9	49.4	44.2	57.4	57.2	58.1	58.1	56.8	55.5	59.8	59.5	59.8	59.4	60.2	59.5
16....	56.0	51.4	44.1	53.9	53.6	53.8	53.8	54.3	53.6	56.5	56.5	55.9	56.4	56.8	57.6
23....	52.6	51.7	44.4	49.6	49.7	50.5	50.5	51.7	51.9	53.5	53.3	53.4	52.9	54.3	56.3
30....	50.5	49.7	44.3	47.6	47.7	47.4	47.5	49.0	49.1	51.4	52.0	50.7	50.6	52.2	55.0
Nov. 6....	48.1	47.9	45.5	44.1	44.0	45 6	45.4	47.2	47.2	49.0	49.1	48.9	48.0	48.7	52.4
13....	46.7	46.3	45.6	40.7	40.7	42.5	42.4	44.7	44.2	45.4	45.7	45.8	45 0	47.8	51.0
20....	45.0	43.9	45.2	40.4	40.9	40.6	40.9	42.0	43.6	43.0	43.3	44.6	44.2	45.7	49.7
27....	43.4	43.0	43.7	36.0	36.3	37.2	37.4	40.2	39.7	40.6	40.9	39.9	40.6	43.4	48.1
Dec. 4....	38.4	38.8	41.1	35.0	35 6	35.8	36.5	38.4	38.4	38.0	37.9	38.4	38.8	41.3	45.8
11...	37.0	37.2	41.0	35.4	35.9	35.3	36.4	36.9	38.6	38.5	38.7	36.7	37.3	42.0	44.1
18....	37.1	37.1	39.4	35.7	36.1	34.6	36.8	37.9	39.3	35.9	37.1	36.6	36.4	39.9	43.4
25....	35.9	36.7	39.1	34.7	36.4	35.3	37.1	36.0	38.3	36.9	37.3	36.2	37.1	39.2	42.4

* Five miles from gate-house. † Seven miles from gate-house.

TABLE No. 2.

Temperatures (Fahr.). Lake Cochituate. 1891.

Depth in Feet....	0	5	10	15	20	25	30	35	40	45	50	55	Bot.
April 14th.....	45.2	45.0	44.6	44.6	44.5	44.0	44.0	43.8	43.8	43.8	43.8	43.8	43.8
" 21st.....	55.3	54.5	53.5	48.8	47.3	45.4	44.4	44.1	43.7	43.5	43.2	43.4	43.9
" 29th.....	53.0	53.0	53.0	53.0	53.0	52.0	49.0	46.0	45.0	44.7	44.5	44.0	44.0
May 5th...	53.2	53.2	53.2	53.2	52.6	52.1	46.8	45.0	44.8	44.0	43.8	43.6	43 4
" 12th.....	58.1	55.5	55.2	52.0	51.2	48.9	45.8	45.0	44.8	43.8	43.7	43.4	43.7
" 19th.....	55.5	55.4	55.2	55.0	54.1	50.8	48.1	45.8	45.0	44.3	43.6	43.5	43.4
" 26th.....	63.0	63.0	61.0	58.0	54.2	53.4	48.0	46.7	46.7	45.8	45.0	44.5	44.0
June 2d.....	67.0	65.6	62.7	56.9	54.3	50.7	48.3	46.9	46.0	46.0	44.6	44.5	44.3
" 9th.....	67.0	66.9	66.0	59.3	53.9	50.2	47.6	46.7	45.5	44.9	44.8	44.6	44.4
" 18th.....	71.4	71.1	60.6	57.5	53.9	50.3	48.8	47.7	47.0	46.8	45.0	44.2	43.9
" 23d.....	70.5	69.6	67.0	60.0	55.0	52.0	48.9	47.7	46.6	46.0	45.3	45.0	44.5
" 30th.....	69.7	68.5	67.6	62.5	56.9	52.7	50.9	49.7	48.5	47.6	46.4	45.5	44.8
July 6th.....	70.3	70.2	69.7	64.1	53.6	50.5	48.0	47.6	46.1	45.2	45.0	44.7	43.8
" 13th.....	73.8	72.7	70.0	63.9	54.3	50.9	48.8	47.7	47.4	46.0	45.0	44.2	*43.1
" 21st.....	77.0	76.4	74.8	63.5	53.8	51.1	50.0	48.6	47.8	45.4	44.6	44.0	43.2
" 28th..... ...	74.5	74.4	73.0	64.2	55.6	51.1	48.9	47.8	45.6	44.9	44.0	43.5	43.3
Aug. 4th.....	72.1	72 0	71.4	64.2	57.7	50.9	48.9	47.8	46.7	45.3	44.6	43.8	43.2
" 11th.....	76.8	76.1	74.0	62.4	56.5	52.4	51.3	48.8	47.4	46.3	44.8	43.4	43.4
" 18th.....	74.5	74.4	73.0	64.4	56.2	51.1	49.3	48.2	46.9	45.8	44.3	43.8	43.1
" 25th.....	77.6	77.0	75.2	67.8	58.2	53.7	51.3	48.6	47.0	45.7	44.2	43.1	43.1
Sept. 10th.....	72.7	71.3	68.2	67.9	59.4	51.4	50.6	48.2	47.6	47.4	46.8	45.4	45.4
" 17th.....	69.5	69.0	68.5	67.5	59.0	51.5	50.0	48.5	47.4	45.7	44.6	44.2	44.2
" 23d.....	70.9	70.5	70.0	68.0	61.5	52.0	50.5	48.9	47.6	46.2	45.5	44.0	44.0
" 29th.....	71.8	71.6	71.0	65.5	55.8	50.9	49.5	47.6	45.9	44.7	44.1	43.5	43.5
Oct. 6th.....	67 0	66.9	66.8	66.1	58.4	50.5	48.3	47.5	46.8	45.7	45.1	44.6	44.6
" 13th.....	57.5	57.5	57.5	57.5	54.1	50.8	48.0	46.2	45.4	44.2	43.6	43.4	43.4
" 20th.....	55.6	55.6	55.6	55.4	55.4	54.6	49.4	46.4	45.6	44.7	43.9	43.4	43.4
" 27th.....	49.6	49.6	49.6	49.6	49.6	49.4	49.4	48.3	45.7	44.9	44.1	43.4	43.4
Nov. 3d.....	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.5	46.3	45.1	44.0	43.6	43.6
" 10th.....	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Average	64.4	63.9	62.6	58.8	54.1	50.6	48.5	47.1	46.2	45.3	44.6	44.0	43.8

* Represents observation taken with particular care.

TABLE No. 2—(*Continued*).

Temperatures (Fahr.). Lake Cochituate 1892.

Depth in Feet....	0	5	10	15	20	25	30	35	40	45	50	55	Bot.
April 9th.....	45.4	45.4	45 4	45.3	45.2	44.8	44.6	44.4	44.4	44 3	44.1	44.0	44.0
" 26th.....	49.6	49.5	49.2	48.7	47.8	46.4	45.6	45.5	45 3	45.1	45.0	44.8	44.5
May 3d.....	50.9	50.5	50.2	50.0	49.6	48.5	46.0	45.5	45.3	45.2	45.0	44.9	44.8
" 10th.....	54.2	54 1	54.0	53.5	52.3	50.9	47.7	46.9	46.4	45.9	45.2	44 8	†44.3
" 17th.....	56.9	56.9	56.8	56.6	56.3	53.0	50.4	48.9	47.2	46.4	45 7	45.1	44.6
" 24th.....	55.3	55.3	55.2	55.2	55.0	54.5	50.5	48.6	47.3	46.1	45.6	44.8	44.3
June 1st.....	67.2	65.5	62.2	59.5	57.5	55.5	50.8	50.0	49.5	48.6	46.5	45.3	44.1
" 7th.....	70.7	70.5	69.1	60.5	56.0	54.4	51.5	50.0	49 8	48.5	45.9	44.8	44.1
" 14th	76.0	73.2	71.4	62.0	57.3	55.2	51.0	48.3	47.8	46.9	46.4	45.2	44.1
" 21st.....	75.6	75.4	74.5	64.9	59.2	55.1	53.0	51.5	49.8	48.9	47.7	45 5	44.0
July 6th.....	72.5	72.1	71.6	69.2	58.0	54,3	51.2	49.8	48.6	47.4	46.2	45.7	44.0
" 13th.....	73.3	72.8	72.2	70.8	59.1	54.5	51.7	49.4	47.8	46.9	46.1	45 2	44.0
" 19th.....	76.4	75.0	72.3	70.2	60.5	54.5	52.0	50.7	49.1	47.8	46.6	45.3	44.1
" 25th.....	78.7	76 3	74.6	71.0	58.0	53.7	50 5	49.8	48.3	47.6	46.8	45.3	*44.1
Aug. 2d.....	74.0	73.5	72.6	70.5	59.6	53.0	50.5	49.3	48.6	47.9	46.5	45.8	44.0
" 9th.....	76.0	75.8	75.5	70.6	57.7	53.6	51.0	50.2	49.6	48.3	47.5	45.8	44.0
" 16th.....	77.3	77.3	76.0	73.0	59.0	55.0	51.0	49.0	47.5	47.0	46.0	45.8	44.1
" 22d	76.7	76.3	76.1	71.5	60.6	55.5	50.6	49.5	48.6	47.9	47.3	46.7	44.7
" 30th.....	68.5	68.3	68.2	68.1	61.0	53.5	51.0	49.7	47.8	46.9	46.3	45.2	44.3
Sept. 7th.....	68.3	68.2	68 1	68.0	60.2	54.2	50.5	49.0	47.8	46.7	45.9	45.1	44.3
" 13th.....	67.5	66.8	65.5	64.3	63.6	51.7	50.5	49.4	48.6	47.1	45.9	45.2	43.9
" 20th.....	67.5	67.2	66.8	66.4	63.6	53.7	50.5	48.4	47.1	46.3	45.6	44.8	44.1
" 27th.....	64.6	64.5	64.4	64.4	64.4	60.0	57.2	49.6	47.9	46.5	45.8	45.0	44.3
Oct. 4th.....	59.9	59.7	59.6	59.5	59.4	56.7	51.1	49.4	47.5	46.6	45.9	45.2	44.3
" 11th.....	56.8	56.8	56.7	56.6	56.5	56.1	51.3	49.4	47.5	46.7	45.9	45.2	44.3
" 18th.....	56.5	56.5	56.5	56.5	56.3	55.8	52.4	49.2	47 4	47.5	45.8	45 1	*44.3
" 25th..	53.0	52.8	52.8	52.7	52.6	52.5	52.4	49.9	47.5	46.7	45.8	45.1	44.4
Nov. 1st..	50.6	50.6	50.6	50.5	50.4	50.2	50.1	49.5	47.9	46.6	45.8	45.1	44.5
" 8th.....	48.7	48.7	48.7	48.6	48.5	48,4	48.2	47.5	46.4	45.7	45.3	44.8	44.3
" 15th.....	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4
Average.....	63.8	63.4	62.7	60.8	56.4	53.0	50.4	48.8	47.7	46.8	46.0	45.2	44.3

* Represents observations taken with particular care. † Bottom, May 5th, 44.5.

TABLE No. 2—(*Continued*).

TEMPERATURES (FAHR.). LAKE COCHITUATE. 1893.

DEPTH IN FEET....	0	5	10	15	20	25	30	35	40	45	50	55	60
April 18th.....	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.0	42.1	42 1	42.2	42.2	42.3
" 25th.....	44.4	44.2	44.0	43 8	43.6	43.4	43.3	43.2	43.1	43.0	42 9	42.9	42.8
May 2d.....	46.7	46.4	46.0	45.6	45.2	44.9	44.7	44.5	44.3	44 1	44.0	43.9	43.8
" 9th.....	50 0	48.9	48.4	47.7	47.3	46.5	46.2	45.9	45.8	45.5	45.3	45.8	44.4
" 16th.....	59.3	58.4	53.5	48.8	48.3	48.0	47.3	47.0	47.0	47.0	47.0	46 8	45 5
" 23d.....	64.2	62.8	58.0	54.2	48.5	48.0	47.8	47.2	47.0	47.0	47.0	47.0	45.5
" 31st.....	63.1	62.0	61.3	60.0	51.7	48 0	47.8	47.5	47.5	47.5	47.5	47.2	45.3
June 6th.....	71.3	70.0	64.3	55.2	49.3	48.1	47.0	46.8	46.5	46.3	45.8	45.4	45.1
" 13th.....	73.3	73.2	72.0	59.7	52.2	49.5	49.0	48.7	48.3	48 3	48.3	48.2	45.2
" 20th.....	72.8	72.6	71.5	64.2	63.5	58.0	48.7	48.0	47.5	47.0	47.0	47.0	45.3
" 26th.....	67.8	67.6	67.0	58.4	52.7	49.2	47.6	47.1	46.8	46.3	45.9	45.5	45.1
" 30th.....	63.1	62.5	61 6	57.8	51.1	49.6	47.3	46.9	46.5	46.2	45.7	45.4	44.9
July 11th.....	75.2	74.5	73.8	67.4	51.5	49.8	48.0	47 6	47.2	46.5	45.9	45.4	44.9
" 18th.....	76 3	75 1	74.8	64.2	52.5	50.1	48.4	47.9	47.5	46.7	46.2	45.6	*45.0
" 25th.....	74.5	73.8	73.0	64.2	51.5	49.3	48.1	47.8	47.2	46.7	46.1	45.6	45.0
Aug. 1st	73.5	72.9	72.3	64.8	52.4	49.3	48.0	47.7	47.1	46.5	45.8	45.4	44.9
" 8th.....	74.4	74.0	72 0	66.0	54.0	53.0	52.2	47.8	47.0	46.5	45.9	45.4	45.1
" 15th.....	74 6	74.1	71.5	69.0	56.0	53.2	48.9	47.8	47.1	46.5	45.9	45.4	44.9
" 26th.....	71.3	70.2	70.0	68.5	56.4	52.8	51.2	48.8	47.3	47.0	47.0	45.7	44.8
" 29th.....	69.8	67.5	62 3	58.4	52.5	49.7	48.9	48.6	47.9	47.3	46.5	45.8	44.9
Sept. 6th.....	68.2	68.1	67.9	66.8	62.5	56.2	49.1	48.3	47.7	46.9	46.4	45.8	45.0
" 12th.....	66.8	66.4	66.4	65.0	58 3	52.5	50.3	48.3	48.0	47.2	47.0	47.0	44.8
" 19th	65.2	65 2	65.2	64.5	58.3	53.8	51.2	49.8	48.5	48.5	48.5	47.8	44 8
" 26th.....	63 2	63.1	63.0	62.6	62.1	55.8	49.5	48 4	47.5	46.8	46.1	45 6	44.9
Oct. 3d.....	58.4	58.2	58.0	57.8	57.5	53.7	49.4	48.2	47.5	46.9	46.3	45.6	44 9
" 10th.....	59.0	59.0	58.8	58.2	58.2	54.5	51.5	50.8	50.8	50.8	50.8	49.8	45.1
" 17th	56.5	56.5	56 5	56.5	56.4	54.3	52.8	49.0	47.9	47 1	46.2	45.7	44.9
" 24th.....	56.4	56.3	56.1	56.0	55.8	55 1	54.4	49.7	48.5	47.6	46.9	46.2	45.4
" 31st.....	53.4	53.4	53.4	53.4	53.4	53.4	53.4	50.1	48.5	47.7	46.9	46.2	45.0
Nov. 7th.....	50.6	50.6	50.6	50.6	50.6	50.6	50.2	50.0	48.5	47.0	47.0	47.0	45.7
" 16th.....	46.1	46.1	46.1	46.1	46.1	46.1	46.1	45.9	45.8	45.7	45.7	45.5	45.3
" 21st.....	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.2
Average.....	62 4	61.9	60.8	57 6	52.7	50.5	48.7	47.5	47.0	46.5	46.3	45.9	45.0

* Represents observation taken with particular care.

TABLE No. 2—(*Continued*).

Temperatures (Fahr.). Lake Cochituate. 1894.

Depth in Feet	0	5	10	15	20	25	30	35	40	45	50	55	Bot.
April 17th.....	43.8	43.5	43.5	42.8	42.5	42.1	42.1	41.7	41.7	41.7	41.7	41.7	41.7
" 24th.....	50.2	50.0	49.2	48.8	47.3	45.8	44.5	43.0	42.2	41.8	41.8	41.8	*41.3
May 1st.....	57.0	56.5	54.9	50.0	47.1	45.7	44.0	43.6	43.2	42.9	42.5	42.1	41.5
" 8th.....	61.1	60.7	60.0	54.4	48.6	46.8	44.3	43.9	43.3	42.8	42.4	42.1	41.5
" 16th.....	61.2	61.0	59.7	58.8	56.9	47 2	45.9	45 0	44.6	43.9	43.7	43.7	41.8
" 23d.....	61.5	60.3	59.1	57.6	51.0	47.2	44.6	43.9	43.3	42.8	42.3	41.9	41.5
" 31st.....	62.3	61.9	61.5	57.8	51.5	47.2	45.5	44.6	43.9	43.4	42.7	42.3	41.8
June 6th.....	62.5	62.1	61.4	58.6	52.3	48.0	45.6	44.8	44.2	43.8	42.9	42.5	41.9
" 15th.....	71.5	69.5	67.6	59.8	53.4	49.4	47.0	46.1	45.2	44.4	43.2	42.7	42.2
" 21st.....	75.7	74.2	71.6	60.5	54.2	50 5	48.1	47.2	45.9	44.7	43.5	42.9	42.4
" 26th.....	73.3	73.0	71.2	62.7	53.5	51.7	48.2	47.5	47.3	47.1	46.8	46.8	42.3
July 5th.....	77.1	75.8	72.6	65.0	53.5	49.1	47.3	46.0	45.2	44.5	43.9	43.1	42.6
" 11th.....	76.6	76.2	74.5	70.6	56.8	52.3	48.9	48.7	48.5	48.5	48.1	47.5	42.7
" 18th.....	77.6	77.1	76.0	69.5	56.0	50.7	48.1	47.8	47.5	47.2	46.6	46.0	42.8
" 25th.....	78.6	78.1	77.4	68.5	55.2	49.2	47.5	46.9	46.4	45.8	45.0	44.5	42.9
Aug. 1st.....	79.5	79.0	78.8	67.2	54.3	47.6	46.9	46.1	45.3	44.5	43.6	43.2	42.8
" 7th.....	78.5	77.3	75.8	64.7	52.5	49.2	47.5	46.4	45.6	44.7	44.1	43.5	43.0
" 15th.....	73.6	72.8	72.3	65.4	50.8	49.2	47.8	46.5	45.6	44.9	44.3	43.7	43.1
" 22d.....	70.2	70.1	70.0	69.2	54.9	50.5	47.4	46.5	45.8	45.0	44 2	43.6	43.0
" 29th.....	70.5	70.2	70.1	70.0	51.5	49.0	47.1	46.2	45.4	44.5	43.8	43.3	42.9
Sept. 5th.....	68.8	68.6	67.9	67.5	52.2	49.7	47.4	46.3	45.1	44.4	43·5	43.2	42.9
" 12th.....	69.7	68.9	67.7	65.6	53 1	49.9	47.3	46.1	45.2	44.4	43 7	43.3	42.8
" 19th.....	68.3	67.6	66.8	66.4	52.2	49.7	45.5	45.0	44.4	43.9	43.5	43.2	42.9
" 26th.....	65.4	64.9	63.4	62.3	52.5	49.3	46 4	45.5	44.8	44.1	43.2	43.2	42.9
Oct. 3d.....	61.8	61.7	61.6	61 5	53.5	50.5	46.8	46.1	45.3	44.4	43.6	43.2	43.0
" 10th.....	59 2	59.1	58.9	57.8	49.0	48.2	46.9	46.0	45.3	44 6	43.9	43.4	43.1
" 17th.....	53.5	53.5	53.5	53.3	53.5	52.9	52.4	48.1	46.5	45.2	44.4	43.7	43.3
" 24th.....	52.7	52.7	52.6	52.5	52.4	50.0	48.6	47.7	46.3	45.1	44.3	43.8	43.4
" 31st.....	51.5	51.5	51.4	50.8	50.3	49.5	48.2	47.7	46.6	45.4	44.5	43.8	43.3
Nov. 7th.....	47.4	47.4	47.4	47.4	47.4	47.4	47.3	47.3	47.3	47.3	47.3	47.3	47.3
Average.....	66.4	64.8	63.9	60.2	52.0	48.8	46.8	45.9	45.2	44.6	44.0	43.6	42.7

* Bottom, 41.4.

TABLE No. 3.

LAKE COCHITUATE—TEMPERATURES (FAHR.) TAKEN WITH THE THERMOPHONE.

	Northern Division.													Middle Div.	Southern Division.		
	December 21, 1894.						Feb. 26, 1895.	March 14, 1895.		Mar. 29, 1895.	Apr. 10, 1895, 11 A. M.	Apr. 13, 1895, 11 A. M.	Apr. 15, 1895.	Apr. 18, 1895.	Apr. 22, 1895.	Feb. 26, 1895.	February 26, 1895.		Mar. 15, 1895.
Depth in feet.	At buoy near gate-house.	100 ft. west of buoy.	Half way from buoy to opposite shore.	300 ft. from shore opposite the gate-house.	Point near the shore opposite the gate-house.	Point near the shore opposite the gate-house.	At buoy.	At buoy.	Half way from buoy to opposite shore.	At buoy.	At buoy.	At buoy.	At buoy.	At buoy.	At buoy.	About the middle of the Southern Division.	Near the B. & A. R. R. bridge.	About the middle of the Southern Division.
Surface..	32.8	33.50	33.80	33.50	33.80	33.40	32.45	33.05	32.15	.....	33.15	39.70	39.85	42.85	44.55	32.25	32.55	32.15	32.15
1.....	35.2	35.40	35.50	36.60	36.70	36.40	32.55	.....	.....	33.20	.....	.....	.....	.....	.....	32.65	32.65	32.25	32.85
2.....	35.7	36.60	37.60	37.55	37 70	37.40	32.75	33.80	32.85	35.60	38.40	39.70	39.85	42.35	44.45	32.75	32.80	32.55	33.80
3.....	37.3	37.40	38.05	37.65	37.85	37.90	33.40	.....	.....	36.50	.....	.....	.....	.....	.....	33.70	33.60	33.60	
4.....	37.7	37.45	38.20	37.70	38.00	38.15	34.55	35 70	35.40	36.80	38.60	39 70	39.75	42.15	44.45	34.55	35.10	34.95	34.80
5.....	37.8	37.55	38.30	37.70	38.05	38.35	35.15	.....	.....	37.00	.....	.....	.....	.....	.....	35.85	36.90	35.70	
6.....	37.8	37.75	.....	.....	.....	.....	35.55	36.25	36.15	37.00	38.70	39.70	39.70	41.85	44.45	36.95	37.70	36.90	35.10
7.....	37.9	37.85	.....	.....	.....	.....	36.75	.....	.....	37.00	.....	.....	.....	.....	.....	36.05	38.10	37.50	
8.....	37.9	37.90	.....	.....	.....	.....	38.20	36.65	36.60	37.00	38 70	39.30	39 70	41.75	43.55	36.30	38.80	37.90	35.45
9.....	37.9	37.90	.....	.....	.....	.....	38.95	.....	.....	36.90	.....	.....	.....	.....	.....	36.50	39.00	38.30	
10.....	38.0	37.85	38.40	37.75	38.20	38.40	39.00	36.85	36.80	36.90	38 70	39.15	39.75	41 65	43.55	36.55	39.00	38.50	35.95
11.....	.....	.....	.....	.....	.....	.....	39.00	.....	.....	37.00	.....	.....	.....	.....	.....	36.55	.....	38.60	
12.....	.....	.....	.....	.....	.....	.....	39.05	37.15	37 10	37.20	.....	39.10	39.65	41.60	43.55	36.70	.....	38.70	36.95
13.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	37 30	.....	.....	.....	.....	.....	36.90	.....	38.80	
14.....	.....	.....	.....	.....	.....	.....	.....	38.45	38.25	37.30	.....	.....	39.55	41.35	43.55	37.05	.....	38.85	37.95
15.....	38.1	37.85	38.40	37.75	38.25	bot. 38.45	39.10	38.75	.....	37.30	38.70	39.05	.....	.....	.....	37.40	39.00	39.10	
16.....	.....	.....	.....	.....	.....	.....	.....	38.85	38.95	37.50	.....	.....	39.50	41.15	43.55	37.55	.....	39.10	38.85
17.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	37.60	.....	.....	.....	.....	.....	37.80	.....	bot. 39.30	

17.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	37.60	.....	.....	.....	.....	.....	.....	.....	.....	
18.....	.....	.....	.....	.....	.....	.....	.....	39.00	39.05	37.80	.....	.....	39.50	41.05	43.35	37.95	.....	.....	39.35
19.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	37.80	.....	.....	.....	.....	.....	38.10	.....	.....	
20.....	38.2	37.85	38.40	37.85	38.25	.....	39.30	39.05	39.05	37 90	38.60	39 05	39.35	41.05	43.00	38.20	39.00	.....	39.40
21.....	....	.....	.....	.....	.....	.....	.....	.....	.....	38.20	.....	.....	.....	.....	.....	38.30	.....	.....	
22.....	.....	.....	.....	.....	.....	.....	.....	.....	.... .	38.50	.....	.... ..	.....	.....	.....	38.40	.....	.....	39.40
23.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.70	.....	.....	.....	.....	.....	38.45			
24.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.80	.....	.....	.....	.....	.....	38.45			
25.....	38.25	37.90	38.45	37.85	.....	.....	39.30	39.15	39.20	38.80	38.60	39.05	39.35	41.00	42.45	38.50	39.00	.....	39.45
26.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.50			
27.....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.60			
					bot.														
28.....	.....	.....	.....	.....	38.30	.....	.....	.....	.....	39.30	.....	.....	.....	.....	.....	38.60			
29.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.65			
30.....	38.35	37.95	38.50	37.85	.....	.....	39.40	39.45	39.45	39.30	38.60	39.00	39.35	40.65	41.55	38.65	39.00	.....	39.50
31.....	.....	.....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38 70			
32.....	.....	. ...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.70			
33.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.80			
																bot.			
34.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.85			
35.....	38.40	38.00	38.50	37.90	....	.....	39.40	39.55	39.60	39.30	38.90	39.00	39.35	40.50	41.35	.....	39.00	.....	39.55
40.....	38.55	38.20	38.55	38.00	....	.....	39.50	39.60	39.65	39.50	38.95	39.00	39.35	40.35	41.25	.....	39.00	.....	39.55
45.....	38.70	38.40	38.70	38.70	.....	.....	39.80	39.95	39.90	39.60	39.00	38.75	39.35	40.30	41.15	.....	39.00	.....	39.60
				bot.															
46½....	.....	.....	.....	38.90															
48.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.65	.....	.....	.....	.....	.....	.....	
50.....	38.90	38.45	39.25	.....	.....	.....	40.20	40.15	40.30	39.90	39.20	38.65	39.35	40.30	41.05	.....	39.30	.....	39.65
51.....	39.10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
	bot.																		
52.....	39.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.65							
			bot.																
53.....	.....	.....	39.30																
		bot.							bot.										
54.....	.....	38.90	.....	.....	.....	.....	.....	.....	40.55										
									mud.										
55.....	.....	.....	.....	.....	.....	.....	40.60	40.65	40.65	40.20	39.40	38.65	39.35	40.25	41.05	.....	39.50	.....	39.85
57.....	.....	.....	.....	... ..	.....	.....	.....	.....	.....	.....	39.70								
							bot.	bot.											
58.....	.....	.....	.....	.....	.....	.....	40.80	40.75	.....	40.40	39 80	38.65							
								mud.		bot.							bot.		
60.....	.....	.....	.....	.....	.....	.....	.....	40.85	.....	40.70	40.00	.....	39.35	40.20	41.05	.....	39.55	.....	40.65
										mud.									
61.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.75	40.00								
											bot.	bot.	bot.	bot.	bot.				
62.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	... .	40.60	38.55	39.35	40.15	41.05				
																			bot.
63.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.95
														mud.	mud.	.....	.....	.....	mud.
														40.05	40.55				41.05

TABLE No. 4.

BOSTON WATER-WORKS.—TEMPERATURES (FAHR.) TAKEN WITH THE THERMOPHONE.

	BASIN 2.					BASIN 3.					BASIN 4.			BASIN 6.			
	Jan. 25, 1895.	February 25, 1895.			April 11, 1895, 4 P. M.	Jan. 25, 1895.	February 23, 1895.			April 12, 1895. 10 A. M	Jan. 28, 1895.	Feb. 12, 1895.	April 11, 1895. 12 M.	February 15, 1895.			April 11, 1895. 2 P. M.
Depth in feet.	Buoy about 150 feet from dam.	Abont 100 feet from gate-house.	Buoy about 150 feet from dam.	Two-thirds of distance from dam towards bridge.	At buoy.	Buoy 500 feet from dam.	Buoy 500 feet from dam.	Half way from dam to railroad bridge.	Near railroad bridge.	At buoy.	Buoy 150 feet from gate-house.	Buoy 150 feet from gate-house.	At buoy.	Near south end of dam.	Buoy near north end of dam.	Half way from dam to island.	At buoy.
Surface..	32.50	.....	.....	.....	43.15	33.40	.....	.....	.....	39.45	32.30	32.00	38.75	.....	.....	.....	38.20
1.....	32.90	32.55	32.55	32.25	.....	33.50	32.35	32.25	.....	.....	32.70	32.20	.....	33.10	33.00	32.75	
2.....	33.10	32.65	32.75	32.35	43.15	33.60	32.50	32.65	32.65	39.45	33.20	32.20	38.60	34.10	33.00	32.85	38.15
3.....	33.30	32.80	32.90	32.65	.....	33.70	33.50	32.80	32.80	.....	33.40	32.20	.....	34.45	33.40	32 90	
4.....	33.40	32.90	33.00	32.80	43.10	33.90	33.50	33.10	33.05	39.45	33.50	32.20	38.55	34.75	33.85	33.00	38.15
5.....	33.40	33.10	33.10	33.00	.....	34.00	33.60	33.45	33.70	.....	33.60	32.60	.....	35.15	34.60	33.60	
6.....	33.40	33.25	33.20	33.20	42.80	34.80	34.00	33.75	34.10	39.45	33.70	32.90	38 40	35.45	35.05	34.15	38.10
7.....	33.45	33.60	33.35	33.60	.....	35.20	34.10	34.00	34.55	.....	34.30	33.60	.....	36.45	35.45	34.65	
7½.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35.35	
8.....	33.70	33.80	33.60	33.85	42.75	36.30	34.20	34.65	35.05	39.25	35.50	33.80	38.40	36.85	35.95	35.75	37.90
8½.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	36.75		
9.....	34.50	34.80 bot.	34.55	35.05	.....	36.90	35.25	35.10	35.55	.....	36.20	34.30	.....	37.30	37.05	36.15	
10.....	35.30	34 95	36.95	36.85 bot.	42.65	37.40	35.70	35.95	36.05	39.25	37.00	35.10	38.35	37.90	37.50	36.60	37.90
10½.....	.....	.....	.....	37.00													
11.....	36.80	.....	38.00	.....	.....	37.80	36.70	36.35	36.85	.....	37.30	35.90	.....	38.40	37.90	36.95	
11.....	38.50																
12.....	39.15	.....	.....	.....	42.60	38.50	37.40	37.40	38.20	39.25	37.30	36.50	38 30	38.80	38.35	37.35	37.95

12½	.....	.....	.....	bot. 38.50	.....	.....	.....	38.70	38.60	38.60	.....	37.50	36.70	.....	39.20	38.50	37.50	
13	.....	39.30	.....	.....	.....	.....	.....											
		bot.																
14	.....	39.30	.....	.....	.....	.....	42.45	.....	39.50	39.40	39.00	39.20	37.60	36.95	38.30	39.50	38.75	37.90	38.00
15	.....	.....	.....	.....	.....	.....	.....	39.20	39.70	39.60	39.60	.....	37.70	37.20	.....	39.90	39.00	38.20	
							bot.												
16	.....	.....	.....	.....	.....	.....	42.45	.....	39.80	39.80	.....	39.15	37.90	37.40	38.30	40.15	39.10	38.40	38.00
											bot.								
16½	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.60								
17	.....	.....	.....	.....	.....	.....	.....	.....	39.90	39.90	.....	.....	38.10	37.70	.....	40.40	39.20	38.65	
								bot.								bot.			
18	.....	.....	.....	.....	.....	.....	.....	39.70	40.00	40.05	.....	39.10	38.30	37.85	38.30	40.60	39.35	38.75	38.00
										bot.									
19	.....	.....	.....	.....	.....	.....	.....	.....	40.00	40.50	.....	.....	38.60	38.20	.....	.....	39.50	38.80	
20	.....	.....	.....	.....	.....	.....	.....	.....	40.10	.....	.....	39.10	38.70	38.40	39.30	.....	39.70	38.90	38.00
									bot.										
21	.....	.....	.....	.....	.....	.....	.....	.....	40.25	.....	.....	.....	38.90	38.70	.....	.....	40.00	38.95	
22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.10	39.10	38.90	38.30	.....	40.20	39.10	38.00
23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.10	39.20	.....	.....	40.50	39.50	
												bot.							
24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.10	39.40	39.35	38.30	.....	40.60	39.75	38.00
																		bot.	
25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.60	39.40	.....	.....	40.60	39.80	
26	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.70	39.50	38.30	.....	40.60	.....	38.00
27	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.55	.....	.....	40.60		
28	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.80	39.60	38.30	.....	40.60	.....	38.00
29	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.70	.....	.....	40.60		
														bot.					
30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.80	39.70	38.30	.....	40.65	.....	38.00
													bot.						
31	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	39.80	.....	.....	.....	.....	.....	
32	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.30	.....	.....	.....	38.00
33	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.80		
34	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.30	.....	.....	.....	38.00
35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.90		
36	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.30	.....	.....	.....	38.00
37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.95		
38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.30	.....	.....	.....	38.00
																	bot.		
38½	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	41.00		
40	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.30	.....	.....	.....	37.95
42	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.35	.....	.....	.....	37.90
															bot.				
44	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.40	.....	.....	.....	37.95
46	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.05
48	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.05
																			bot.
50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	38.05

TABLE No. 5.—Temperatures (Fahr.). Lake Winnepesaukee, Thermophone.

Between Sandy and Welch Islands, Aug. 25, 1892.		North and N. E. of Rattlesnake Island.	Aug. 27, 1892.	North of Barndoor Island.	March 4, 1895.	Between Baker's Island and Ship Island.	March 5, 1895.	Between Rattlesnake and Parker islands.	March 6, 1895.	Near Rattlesnake Island.	March 5, 1895.	"The Broads."	March 7, 1895.	Between Welch and Sandy islands.	March 7, 1895.
Surface.	73.0	Surface.	68.5	2 ft.	32.95	1	32.20	5	32.85	5	32.85	0	32.10	0	32.25
40 ft.	64.5[1]	25 ft.	68.3	3	33.10	5	32.75	7	33.10	7½	33.10	2	32.35	2	32.35
80 "	56.0[2]	50 "	59.0	4	33.20	7	33.10	10	33.20	10	33.25	4	32.90	4	32.90
		65 "	57.1	5	33.20	10	33.30	12	33.20	12½	33.30	6	33.00	6	33.00
		75 "	56.2	6	33.80	12	33.60	15	33.20	15	33.30	8	33.05	8	33.15
		105 "	55.0	7	33.95	14	33.70	17	33.30	20	33.35	9	33.05	10	33.15
		112 "[3]	55.0	8	34.00	16	33.80	20	33.40	25	33.75	10	32.95	12	33.20
		125 "[3]	55 0	9	34.00	18	33.95	25	33.90	30	34.05	11	33.00	14	33.25
		135 "[3]	55.0	10	34.00	20	34.05	30	34.10	35	34.30	12	33.00	16	33.35
		145 "[3]	54.0	11	34.00	22	34.10	35	34.40	40	34.55	14	33.00	18	33.35
		.....	.....	12	34.00	24	34.10	40	34.55	45	34.70	16	34.00	20	33.40
		.....	.....	13	34.00	29	34.45	45	34.90	50	34.85	18	33.10	22	33.45
		.....	.....	14	34.00	32	34.55	50 bot.	35.00	55	35.00	20	33.25	24	33.50
		.....	.....	15	34.00	35	34.65	.....	.....	60	35.10	22	33.35	26	33.55
		.....	.....	16	34.05	40	34.80	.....	.....	65	35.25	24	33.50	28	33.65
		.....	.....	17	34.05	45	35.00	.....	.....	70	35.30	26	33.60	30	33.80
		.....	.....	18	34.05	50	35.10	.....	.....	75	35.30	28	33.80	32	33.90
		.....	.....	19	34.15	55	35.10	.....	.....	80	35.35	30	33.90	34	33.95
		.....	.....	20	34.15	60	35.30	.....	.....	85	35.40	32	34.05	36	34.00
		.....	.....	22	34.25	65	35.40	.....	.....	90	35 45	34	34.15	38	34.20
		.....	.....	25	34.35	70 bot.[4]	35.40	.....	.....	95	35.55	35 bot	34.25	40	34.30
		.....	.....	27	34.55	.....	.....	.....	.....	100	35.65	mud.	34.30	42	34.35
		.....	.....	30	34.55	.....	.....	.....	.....	105	35.75	.....	.....	44	34.40
		.....	.....	32	34.65	.....	.....	.....	.....	110	35.80	.....	.....	46	34.50
		.....	.....	34	34.70	.....	.....	.....	.....	115	35.90	.....	.....	48	34.65
		.....	.....	36	34.70	.....	.....	.....	.....	120	35.95	.....	.....	50	34.65
		.....	.....	38	35.00	.....	.....	.....	.....	125	35.95	.....	.....	52	34.75
		.....	.....	40	35.00	.....	.....	.....	.....	130	36.05	.....	.....	54	34.85
		.....	.....	42	35.10	.....	.....	.....	.....	135	36.15	.....	.....	56	34.85
		.....	.....	44	35.10	.....	.....	.....	.....	140	36 25	.....	.....	58	34.90
		.....	.....	46	35.10	.....	.....	.....	.....	141 bot.	36.25	.....	.....	60	35.00
		.....	.....	48	35.20	.....	.....	.....	.....	142 mud[5]	36.70	.....	.....	62	35.05
		.....	.....	50	35 20	.....	.....	.....	.....	.....	.....	.....	.....	64	35.10
		.....	.....	52 bot.	35.25	.....	.....	.....	.....	.....	.....	.....	.....	66	35.10
		.....	.....	mud.	35.60	.....	.....	.....	.....	.....	.....	.....	.....	68	35.25
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	70	35.25
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	72	35.25
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	74	35.35
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	76	35.40
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	79 bot.	35.50
		.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	mud.[6]	35.70

TABLE No. 5.—Temperatures (Fahr.). Lake Winnepesaukee, Thermophone—(*Continued*).

East of Long Island.	March 7, 1895.	200 ft. nearer Rugged Island.	March 7, 1895.	Between Bear and Five-Mile islands.	March 7, 1895.	Between Beaver and Black Cat islands.	March 7, 1895.	Near wharf at Center Harbor.	March 8, 1895.	Between Weir's and Pitchwood Island.	March 8, 1895.	North West Bay entrance.	March 8, 1895.	Near Meredith village.	March 8, 1895.
0	32.20	0	32.10	0	32.30	0	32.20	0	32.45	0	32.20	0	32.35	0	32.20
2	32.20	2	32.25	2	32.45	2	32.25	2	32.45	2	32.25	2	32.40	2	32.45
4	32.50	4	32.60	4	32.90	4	32.65	3	32.70	4	32.60	4	32.70	4	33.20
6	32.80	6	32.90	6	33.20	6	33.00	4	32.80	6	33.40	6	33.10	6	33.35
8	33.05	8	33.10	8	33.30	8	33.20	5	33.10	8	33.55	8	33.40	8	33.40
10	33.10	10	33.15	10	33.40	10	33.35	6	33.25	10	33.95	10	33.75	10	33.45
12	33.20	12	33.20	12	33.45	12	33.55	7	33.35	12	34.20	12	33.90	12	33.55
14	33.30	14	33.30	14	33.50	14	33.60	8	33.45	14	34.30	14	34.20	14	33.85
16	33.35	16	33.35	16	33.55	16	33.75	9	33.55	16	34.55	16	34.40	16	33.90
18	33.55	17	33.40	18	33.60	18	33.80	10	33.55	18	34.65	18	34.50	18	34.25
18.5	34.75	17.5	33.50	20	33.70	20	33.85	11	33.60	20	34.70	20	34.65	20	34.35
19	35.00	18	33.60	25	33.85	25	33.90	12	33.60	22	34.80	22	34.75	22	34.55
19.5	35.25	18.5	33.90	30	34.00	30	34.15	14	33.70	24	34.80	24	34.80	24	34.65
19.7	35.75	18.7	34.65	35	34.20	35	34.30	16	33.85	26	34.85	26	34.85	26	34.70
20	36.25	19	35.40	40	34.50	40	34.55	17	34.05	28	34.90	28	34.90	28 bot.	34.75
20.5	36.70	19 5	36.00	45	34.80	45	34.95	18	34.15	30	34.95	30	34.95	mud.	35.25
21	36.85	20	36 35	50	35.25	47.5	35.60	19	34.40	32	35.00	32	35.05	.....	.....
21.5	36.85	20.5	36.50	55	35.55	50	35.75	20	34.95	34	35.05	34	35.10	.....	.....
22	36.90	21	36.75	60	35.70	52.5	36.10	21	35.90	36	35.10	36	35.10	.....	.....
23	36.95	22	37.00	65	35.75	55	36.20	22	37.30	38	35.20	38	35.15	.....	.....
24	37.15	24	37.05	70	35.85	57.5	36.30	23	37.80	40	35.25	40	35.20	.....	.....
26	37.20	26	37.15	75	36.10	60 bot.	36.35	24	38.60	42	35.30	42	35.25	.....	.....
28	37.20	28	37.20	80	36.15	mud.	36.60	25	39.05	44	35.35	44	35.25	.....	.....
30	37.25	30	37.20	85	36.25	.....	.....	26	39.25	46	35.35	46	35.30	.....	.....
32	37.25	32	37.25	90	36.35	.....	.....	26.5 bot.	39.30	47 bot.	35.35	47 bot	35.35	.....	.....
33 bot.	37.25	34	37.25	95	36.50	.....	.....	mud.	39.35	mud.	35.55	mud.	35.35	.....	.....
mud.	37.25	36	37.25	100 bot.	36.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	40	37.30	mud.	36 95	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	42	37.35	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	44 bot.	37.50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	mud.	37.80	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
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[1] Mean of two observations. [2] Mean of four observations. [3] Bottom temperatures. [5] Thermometer at bottom, 35.70? [6] Thermometer at bottom, 35.5?

TABLE No. 6.

Temperatures (Fahr.) Taken With the Thermophone.

Dan Hole Pond.		Squam Lake.						Jamaica Pond, Boston, Mass.			Crystal Lake, Newton Centre, Mass.	
⅛ mile from east end. Feet.	March 6, 1895.	500 ft. east of Sturtevant Island.	March 8, 1895.	North of last station.	March 8, 1895.	Northwest shore.	March 8, 1895.		*a.* 500 ft	*b.* apart.	Feet.	March 14, 1895.
0	32.50	2	32.55	0	32.25	0	32.40	0	32.4		0	32.15
2	33.45	4	32.85	2	32.30	2	32.45	1		32.2	1	33.90
3	34.10	5	35.45	3	33.15	3	32.95	1½		34.7	1½	34.30
4	34.50	6	35.85	4	33.45	4	34.65	2	34.2	35.1	2	35.75
5	35.20	7	36.15	5	34.65	5	35.15	2½		36.1	2½	37.10
6	35.35	8	36.45	6	35.70	6	35.70	3	35.7	36.5	3	39.15
7	35.80	9	37.10	7	36.30	7	36.20	4	36.2	36.6	3½	39.50
8	36.05	10	37.35	8	36.80	8	36.70	5	36.6	36.7	4	39.75
9	36.10	11	37.55	9	36.85	9	36.85	6	37.35	37 40	5	39.85
10	36.15	12	37.60	10	37.15	10	37 10	7	37.75	37.95	6	39.75
12	36.20	13	37.70	11	37.25	11	37.25	8	38.15	38.45	6½	39.75
15	36.25	14	37.80	12	37.50	12	37.35	9	38.35	38.79	7	39.80
17	36.30	15	37.85	14	37.70	14	37.45	10	38.65	38.75	8	39.80
20	36.30	16	37.90	16	37.80	16	37.60	11	38.75	38.80	10	39.85
25	36.30	17 bot.	37.95	18	37.85	18	37.75	12	38.95	38.85	12	40.05

30.....	36.35	Mud.....	38.10	20.....	37.90	20.....	37.75	15.....	39.05	38.85	14.....	40.05	
40.....	36.35	.....	.....	22.....	38.05	22.....	37.85	17.....	39.10	.. ..	16.....	40.10	
50.....	36.45	.....	.....	24.....	38.15	24.....	37.95	20.....	39.10	38.95	18.....	40.10	
55.....	36.55	.....	.....	26.....	38.20	26.....	38.10	25.....	39.10	39.05	20.	40.00	
60.....	36.60	.....	.....	28.....	38.55	28.....	38.20	30.....	39.15	39.15	22.....	39.95	
65.	36.70	.....	.....	30.....	38.75	30.....	38.40	35.....	39.25	39.20	24.....	40.15	
70.....	36.75	.....	.....	32.....	38.85	32.....	38.70	37.....	39.35 bot.	.....	Mud.....	40.20	
75.....	36.85	.....	.....	34.....	38.95	34.....	38.85	40.....	.. ..	39.30			
80.....	37.00	.....	.....	36.....	39.00	36.....	38.90	41.....	.....	39.45 bot.			
85.....	37.05	.....	.....	38.....	39.05	38.....	39.00	Mud	39.55	39.60			
90.....	37.15	.....	.....	40.....	39.10	40.....	39.05	.....	.....	.....			
95..... .	37.25	.....	.....	42.....	39.10	42.....	39.10	.....	.....	.....			
100.....	37.45	.....	.....	44.....	39.15	44.....	39.15	....	.....	.....			
105.....	37.60	.....	.....	46.....	39.15	46.....	39.15	.....	.....	.....			
109 bot.....	37.85	.....	.....	48.....	39.15	48.....	39.20	.....	.....	.....			
Mud.	38.05	.....	.....	50.....	39.20	49 bot.....	39.25	.....	.....	.....			
....	.....	.....	.....	52.....	39.20	Mud	39.60	.....	.....	.....			
.....	.....	.....	.....	54.....	39.20	.....	.....	.....	.....	.....			
.....	.....	.....	.....	56.....	39.20	.....	.....	.....	.....	.....			
.....	.....	.....	.....	58.....	39.20	.....	.....	.....	.....	.....			
.....	.....	.....	.....	59 bot.....	39.25	.....	.....	.....	.....	.....			
.....	.....	....	.....	Mud	39.40	.....	.....	.....	.....	.....			

Small pond fed by springs.

TABLE No 7.

TEMPERATURES IN LAKE SUPERIOR. U. S. LAKE SURVEY, 1871.—NICHOLS.

Date.	Latitude.	Longitude.	Depth in fathoms.	Depth in feet.	Temperature at surface in degrees.		Temperature at bottom, in degrees.	
					Fahr.	Cent.	Fahr.	Cent.
Aug. 7...	46° 53′	86° 43′	127	762	56.5	13.6	38.8	3.8
.....	to	to	129	774	56.0	13.3	38.8	3.8
.....	47° 23′	86° 15′	121	726	53.0	11.7	39.1	3.9
.....	.....	.....	131	786	50.1	10.1	38.8	3.8
.....	.....	.....	74	444	50.8	10.4	38.8	3.8
Aug. 11...	48° 18′	86° 15′	59	354	55.8	13.2	41.3	5.2
Aug. 15...	48° 20′	87° 3′	105	630	49.7	9.8	39.0	3.9
.....	to	to	121	726	49.5	9.7	39.2	4.0
.....	47° 45′	87° 6′	168	1 008	49.2	9.5	39.0	3.9
.....	.....	.....	116	696	50.2	10.1	39.3	4.1
.....	.....	.....	136	816	52.2	11.2	38.9	3.8
.....	.....	.....	158	948	52.9	11.6	33.4 ?	0.8
Aug. 18...	48° 9′	88° 15′	47	282	51.8	11.0	36.8	2.7
.....	to	to	129	774	52.7	11.5	38.9	3.8
.....	47° 36′	87° 42′	136	816	52.3	11.3	38.8	3.8
.....	.....	.....	134	804	50.1	10.1	38.9	3.8
.....	.....	.....	82	492	51.5	10.8	39.0	3.9
Aug. 22...	Near Copper Harbor		148	888	.....	.....	38.7	3.7
.....	.....	.....	20	120	51.3	10.7	39.7	4.3
.....	.....	.....	61	366	55.3	12 9	39.2	4.0
Aug. 29...	48° 42′	87° 47′	73	438	55.0	12.8	38.9	3.8

TABLE No. 8.

TEMPERATURES OF SOME LAKES IN MASSACHUSETTS.—F. P. STEARNS.

	Upper Mystic Lake, Medford.	Jamaica Pond, Boston.	Wenham Lake, Wenham.
Date.	August 23d, 1889.	August 21st, 1889.	July 24th, 1889.
Area.	200 acres.	69 acres.	320 acres.
Maximum depth.	87 ft.	57 ft.	47 ft.
Average depth.	.....	27 ft.	
1 ft.	73.4°	74.1°	74.7°
10 "	71.6	70.7	74.4
15 "	68.9	64.8	74.3
20 "	63.3	52.0	
23 "	.....	47.5	
25 "	56.3	46.0	59.0
30 "	49.6	43.7	
35 "	46.4	.....	53.6
40 "	45.5	.....	
45 "	44.4	42.4	49.6
60 "	42.8		
82 "	42.8		

TABLE No. 9.

Temperatures of Swiss Lakes.—H. B. de Saussure.

Lake.	Date.	Depth. Feet.*	Temperature.	
			Surface. Fahr.	Bottom. Fahr.
Geneva	February 6th, 1777	1 013	42.1	41.7
Geneva	August 5th, 1779	160	70.2	43.0
Thun	July 7th, 1783	373	66.2	41.0
Brientz	July 8th, 1783	533	66.9	40.6
Lucerne	July 28th, ——	640	68.5	40.8
Constance	July 25th, 1784	394	64.6	39.7
Maggiore	July 19th, 1783	357	77.0	44.1
Neuchatel	July 17th, 1779	346	73.6	41.2
Bienne	July 20th, 1779	231	69.3	43.4
Annecy	May 14th, 1780	174	57.9	42.1
Bourget	October 6th, 1784	256	64.2	42.1

*De Saussure's depths are given in Swiss feet which have here been multiplied by 0.9382929, to reduce to English measures.

TABLE No. 10.

Lake Thun.—Fischer-Ooster and Brunner, 1848-49.

English feet.	March 28, 1848.	May 13.	July 3.	August 5.	Sept. 6.	Oct. 28.	Nov. 26.	Feb. 3, 1849.
.....	42.3	59.1	59.6	62.8	65.6	53.4	46.3	40.8
10.7	41.4	51.4	59.0	60.4	61.8	53.2	46.3	41.0
21.3	41.3	49.2	57.2	57.3	59.1	53.0	46.4	41.2
32.0	41.2	48.0	53.2	55.5	57.7	53.0	46.2	41.0
42.6	41.1	46.6	52.1	54.4	56.2	53.2	46.1	40.7
63.9	40.9	44.8	49.6	52.6	53.8	53.0	46.1	40.7
85.3	40.8	44.2	46.3	50.7	50.9	52.1	46.1	40.7
127.9	40.4	41.8	42.3	43.7	43.4	43.6	44.0	40.7
170.5	40.4	41.5	41.4	41.8	41.7	42.1	42.1	41.0
266.5	40.4	40.8	41.0	41.1	41.4	41.0	41.3	40.7
373.0	40.6	40.9	40.9	41 1	41.1	40.8	40.7	40.6
479.6	40.7	40.7	40.8	40.9	40.8	40.9	40.6	40.7
586.3	40.7	40.7	40.8	40.7	40.8			

Lake Thun is known to have been frozen four times, 1363, 1435, 1685 and 1695.

TABLE No. 11.

Temperatures of Lake Geneva.—F. A. Forel.

Depth.		1879.								1880.	
Meters.	Feet.	May 14th.	June 21st.	July 24th.	August 20th.	September 24th.	October 23d.	December 19th.	December 24th.	January 15th.	January 30th.
0	0	49.65	66.40	67.30	71.60	66.55	52.50	42.10	41.70	41.35	41.00
10	32.8	44.95	54.15	58.30	64.40	61.35	52.00	42.10			
20	65.6	44.60	47.65	56.85	54.85	53.95	51.80				
30	98.4	44.40	45.30	53.05	50.90	48.75	50.72				
40	131.2	44.25	43.90	46.20	45.70	45.70	47.10				
50	164.0	43.70	43.35	44.05	44.40	44.60	44.80				
60	196.8	.....	.....	43.35	43.15	43·50	43.90	42.10			
70	229.6	43.00	43.00	42.80	42.80	42.80					
80	262.4	42.60	42.45	42.45	42.45	42.25	43.15				
90	295.2	42.25	41 90	42.10	42.10	41.90	42.80				
100	328.0	41.90	41.70	41.90	41.90	41.70	42.45				
110	360.8	41.70	41.55	41.70	.....	.....	42.25	42.10			
120	393 6	41.55	41.55	41.55	41.70	41.55	42.10				
130	426.4	.....	41.35	41.35	41.55	41.55	41.90				
140	459.2	.....	.....	.....	41.55	41.55	41.70				
150	492.0	.....	.....	.....	.....	41.35	41.70	41.90			
160	524.8	41.35	.....	.....	.....	.....	41.55				
170	557.6	.....	.....	.....	.....	.....	41.35				
200	656.0	.....	.....	.....	.....	41.35	.....	41.55			
220	721.6	41.35									
240	787.2	.....	.....	.....	.....	.....	.....	41.55			
250	820.0	.....	.....	.....	.....	.....	.....	41.35			
260	852.8	.....	41.35								
270	885.6	.....	.....	.....	.....	.....	.....	41.35			
300	984.0	.....	.....	41.35	41.35	.....	41 35				

The surface temperature on January 15th, 1880, was 41.35°, and on January 30th, 41°.

TABLE No. 12.

Temperatures of Some Swiss Lakes.—Forel.

Lake Annecy.			Lake Bourget.		Lake Zurich.		Lake Morat.		
August 13th, 1880.		Sept. 22d, 1883.	September 22d, 1883.		January 25th, 1880.		December 23d, 1879.		Feb. 1st, 1880.
Depth. Feet.	Temperature. Fahrenheit.	Temperature. Fahrenheit.	Depth. Feet.	Temperature. Fahrenheit.	Depth. Feet.	Temperature. Fahrenheit.	Depth. Feet.	Temperature. Fahrenheit.	Temperature. Fahrenheit.
Surface.....	65.8	63.5	Surface.....	65.8	Surface.....	36.4	Surface.....	32.7	32.6
32.8.....	64.9	63.5	32.8.....	64.4	32.8.....	36.7	16 4.....	34.9	35.4
65.6.....	50.5	46.4	65.6.....	52.3	65.6.....	37.2	32.8.....	35.6	35.6
98.4.....	44.1	46.4	131.2.....	43.3	98.4.....	37.7	49.2.....	36.0	36.4
131.2.....	42.8	42.8	196.8.....	42.6	131.4.....	38.3	65.6.....	36.4	36.5
164.0.....	41.9	42.8	262.4.....	42.4	164.0.....	38.5	82.0.....	36.7	36.5
180.4.....	41.9	43.0	377.2.....	42.3	196.8.....	38.7	98.4.....	36.8	36.0
196.8.....	41.0	43.0			229.6.....	38.7	114.8.....	37.0	36.6
			Never frozen.		262.8.....	38.8	131.2.....	37.0	36.9
					295.2.....	38.8	Ice. December 23d, 1879, 4.3 ins.		
					328.0.....	39.0	February 1st, 1880, 14.2 "		
					360.8.....	39.0	Area, 10.6 sq. miles.		
					393.6.....	39.2	Depth, 147 ft.		
					436.2.....	39.2			
					Area, 34 sq. miles.				
					Depth, 468 ft.				
					Frozen once.				

DISCUSSION.

Mr. Fanning. J. T. FANNING, M. Am. Soc. C. E.—This paper emphasizes the necessity of providing outlets at different elevations for reservoirs and particularly storage reservoirs. It is common practice to provide two or three gates. As long ago as 1868 the speaker, realizing this necessity, arranged an adjustable outlet for a storage reservoir of 65 acres area as follows: The main outlet pipe was fitted in a Y joint and placed near the bottom of the reservoir about 20 ft. below the flow line. This adjustable pipe revolved in a vertical plane and was provided with a large strainer bulb and counterweighted so that it could be set readily at any altitude. This was a convenient arrangement by which not only could water be drawn from the level where the best was found, but the strainer could be raised above the water surface and readily cleaned.

Mr. Darrach. C. G. DARRACH, M. Am. Soc. C. E.—The paper is no doubt the most exhaustive treatise upon the subject of the temperature of lakes, and the author's theory of semi-annual vertical circulation is new. Even without experimental data, serious thought upon the subject would naturally lead one to suppose that there would be a tendency to such vertical circulation.

In January, 1883, the speaker took some isolated observations upon the temperature of surface and bottom waters in the Schuylkill River, and in three of the Philadelphia reservoirs. The water had been covered with ice for some time previous to the time of observation. The data taken was as follows:

LOCATION.	AIR.	WATER.			
	Degrees, Fahr.	Surface. Degrees, Fahr.	Bottom. Degrees, Fahr.	Depth. Feet.	Difference.
Fairmount Dam	.....	33.	33.4	12	0.4
Fairmount Reservoir.....	34.	33.2	33.8	12	0.6
Spring Garden Reservoir	34.	33.4	33.8	16	0.4
Roxborough Reservoir	36.	33.	33.4	18	0.4

It will be noticed that the temperature of the water immediately under the ice was somewhat higher than the observations noted by the author.

In 1881 a difference of 12° Fahr. was noted between the temperature of the surface water and the water at a depth of 50 ft. in Druid Hill Reservoir, Baltimore.

The spring and fall equilibrium in the densities of water in deep reservoirs has a tendency to produce a vertical circulation, but the

speaker was not prepared to admit that there is an entire semi-annual overturning. Mr. Darrach.

In August, 1875, (while in company with Messrs. W. J. McAlpine, J. W. Adams, Milnor Roberts, William E. Morris, Solomon W. Roberts and William H. McFadden, one of the numerous commissions on the water supply of Philadelphia), during a visit to Tumbling Run Dam, a feeder to the Schuylkill Canal, it was noticed that the water drawn from a depth of 50 ft. was very offensive, both in taste and odor. After running a short distance in the brook, the disagreeable taste and odor disappeared. Much discussion ensued among the members of the commission as to the cause of the trouble, the catchment area of the reservoir being at that time free from artificial pollution. The speaker suggested that decaying vegetation, infusoria, etc., sank to the lower waters of the reservoir, where, for lack of heat and air, decomposition was suspended, and the water containing this pollution, after being exposed to the atmosphere, was speedily purified.

In the winter and spring of 1881 the water supply of the city of Baltimore was so offensive that a public outcry resulted, and venders of pure spring water reaped a harvest. The water of the city storage reservoirs and mains was drawn off and the trouble temporarily ended.

At the instance of the late Robert K. Martin, M. Am. Soc. C. E., the chief engineer, the speaker visited Baltimore in 1882 and suggested to him that he should waste all surplus water from the bottom of Lake Montebello, the receiving reservoir of the Gunpowder supply, and if possible allow no water to waste over the weir, and that he should allow the supply from Jones' Falls and its receiving reservoir on Druid Hill to waste as formerly over the weir.

Lake Montebello has a depth of 30 ft. Druid Hill Reservoir has a maximum depth of 65 ft. and a capacity of 495 000 000 galls., and at that time the daily consumption from it was 10 000 000 galls. There are two inlets to the Druid Hill Reservoir, one at the upper end and one about the middle, both of them discharging into the reservoir at the bottom. The outlets from this reservoir are three-quarters of a mile from the upper end and 15, 26 and 39 ft. respectively below the surface.

There was no complaint of bad water until the latter part of November, 1882, nearly two years after the water had been drawn down, when the water in Druid Hill Lake was found bad 50 ft. below the surface and the water in all of the other reservoirs was good, Druid Hill being the only one from which a flow or waste from the bottom had not been kept up during the intervening period.

On February 16th, 1883, Mr. Martin advised the speaker that he found the water in Druid Hill lake good at 5, 10 and 15 ft. below the surface, but bad below that, so it would appear that there had been a

Mr. Darrach. partial overturning, but that the bad water was not brought to the surface.

Attention is called to the necessity of making ample provision for drawing off the old water from the bottoms of storage reservoirs and preventing fresh waters from running to waste, especially when it may be found necessary to conserve the rainfall of the catchment area for a longer period than a year.

Mr. Stearns. F. P. STEARNS, M. Am. Soc. C. E.—The speaker believed that the subject of temperature of ponds and lakes is not only of scientific interest, but that it is of much practical importance that engineers connected with water-works should be familiar with the seasonal changes of temperature, particularly those which occur in deep ponds and either produce or prevent vertical currents at different seasons of the year, thereby having an important influence upon the quality of water at different depths.

In a great majority of deep ponds and reservoirs, the lower layers, which are stagnant during the summer and consequently unable to get any fresh supply of oxygen from the air, accumulate free ammonia and other solid and gaseous products of decomposition, and the water in them becomes more and more offensive toward the end of the season of stagnation. It is therefore desirable, in such cases, that the water for use should be taken from near the surface, and that if there is water to be wasted it should be taken from the bottom layers which contain the greater amount of impurity, since the whole body of water will be improved thereby when the whole of the water in the reservoir is thoroughly mingled by the overturning in the autumn.

There are a few deep ponds and reservoirs in which there is so little decomposition that the oxygen in the lower layers is not used up and the products of decomposition do not accumulate. In such cases a water which is both cold and good can be drawn from the lower layers. The ponds and reservoirs of this kind are somewhat rare, but an instance of a natural body of water is furnished by Lake Winnepesaukee, in New Hampshire, in which the water was found to be as good in the summer, at a depth of 110 ft., as at the surface; and an instance of an artificial body is furnished by Reservoir No. 4, of the Boston Water-Works, in which the bottom water is practically of the same quality as that at the surface. Reservoir No. 4 was carefully prepared for the reception of water by the removal of all the soil and vegetable matter, and from the time it was first used, not only has there been no accumulation of the products of decomposition in the bottom layers, but there has been no excessive growth of algæ or other organisms. This is a record which very few natural ponds can furnish, and is a very important argument for the thorough cleaning of storage reservoirs.

The extent to which the products of decomposition have accumulated is well indicated by the amount of free ammonia, and the follow-

ing table gives a number of instances of the amount of free ammonia found at the surface and near the bottom of various ponds and reservoirs during the period of summer stagnation. Mr. Stearns.

Locality.	Date.	Depth of pond or reservoir. Feet.	Depth of deepest sample. Feet.	Free Ammonia.	
				Surface.	Near bottom.
Jamaica Pond, Mass.....	Aug. 14th, 1890...	57	50	0.0000	0.4720
Waban Lake, Mass.....	Aug. 27th, 1889...	36	35	0.0012	0.1760
Lake Cochituate, Mass.....	Sept. 18th, 1890...	65	60	0.0004	0.0689
Wenham Lake, Mass.....	July 24th, 1889..	46	45	0.0000	0.0560
Boston, Mass., Reservoir 4.....	Aug. 31st, 1887...	46	40	0.0000	0.0021
Lake Winnepesaukee, N. H.....	Aug. 28th, 1893...	..	110	0.0000	0.0000

So far as the speaker was aware, the first information regarding the accumulation of free ammonia in the bottom of ponds during the summer was furnished by Professor William Ripley Nichols, to whom the engineering profession is indebted for much knowledge on the subject of water supply. He was aware that a sample of water collected from near the bottom of a deep pond, in October, 1877, contained a large amount of free ammonia, and he did not agree with the statement of another chemist that this sample probably came from the neighborhood of a mass of decaying matter. In May, 1878, he instituted a series of tests which continued for a year, in which the character and the temperature of the water at the surface, mid-depth and bottom of this pond, which had a maximum depth of 46 ft., was determined frequently.* The observations were made weekly during the summer of 1878, and at less frequent intervals during other portions of the year. He determined the seasonal changes in temperature substantially as now known, and discovered the large accumulation of free ammonia in the bottom layers during the summer.

The subjects of temperature of the water of deep ponds and the effects of temperature upon the quality of water of deep ponds have also received extended treatment in the special report of the Massachusetts State Board of Health upon the Examination of Water Supplies, 1890, pages 659–676 and 749–767.

In determining the character of the water of a deep pond or reservoir which it is proposed to use for water supply purposes, much can be learned by analyzing samples of water taken from the bottom layers during the period of stagnation.

The author, at the end of the paper, makes the following statement: "This uniformity of temperature in ordinary lakes takes place at two points in the yearly profile, and at these times the wind effects are felt

* See Health Supplement of Report of Massachusetts Board of Health, Lunacy and Charity for 1879, p. 100; also, *Transactions* of the American Society of Civil Engineers for 1884, p. 76.

Mr. Stearns. to great depths." The speaker agreed with this statement, but he thought it does not go far enough to give a clear idea as to the great and complete overturning which takes place in the spring and to a greater extent in the autumn. As the surface water cools in the autumn and becomes heavier than the water below the surface, vertical currents are produced which extend down to and somewhat beyond the depth where the water is at the same temperature as at the surface. These currents are nearly continuous and extend deeper and deeper as the season advances until some time in November, when they extend to the bottom of the pond. After they have reached the bottom, they continue to keep the water in motion for several weeks until the whole of the water in the pond has reached the temperature of maximum density.

Observations of temperature at different depths when the water is cooling and overturning indicate that the water in the pond may be overturned several times a day, and analyses of samples from different depths show by their uniformity that the water is most thoroughly mingled.

In connection with this subject of the temperature of lakes, it is interesting to compare the annual curves showing the mean temperature of the water and of the air. Such curves applicable to Massachusetts are shown in Fig. 12.

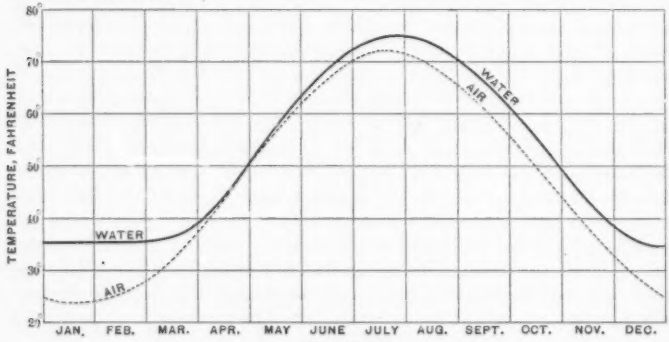

FIG. 12.

It will be noticed at once that the mean temperature of the water is somewhat higher than the mean temperature of the air, although at one point in the spring the two curves coincide. It seems surprising that the temperature of the water in the spring should not be lower than that of the air, since both are rising at the rate of about $\frac{1}{2}^{\circ}$ Fahr. per day, and it would naturally be thought that the air would warm up much more quickly than the water. The reason for the higher mean temperature of the water is not clear, but it seems probable that the direct effect of the sun's heat upon the water has an important influence in producing the results observed.

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THE PHILADELPHIA AND READING TERMINAL RAILROAD AND STATION IN PHILADELPHIA.

By JOSEPH M. WILSON, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE, 1895.

WITH DISCUSSION.

Progress in this country is evidenced in no way more conclusively than in the growth of railways. With their great development, their consolidation into grand trunk lines, the concentration of traffic, and the expansion of suburban travel, the necessity has arisen in cities of the first class for great terminal railway stations in central locations, provided with all the improvements, accommodations and facilities for rapid and effective train service which modern ingenuity can devise. It is believed that an account of the construction of one of these great terminals from its inception to its completion will be of considerable interest to the profession, and it is with this object that the present paper has been prepared.

The Philadelphia and Reading Terminal Railroad was constructed, as its name suggests, for the purpose of providing a proper terminal in

the city of Philadelphia for the Philadelphia and Reading Railroad system. The Philadelphia and Reading Railroad was originally built about the year 1838 as a coal road, extending from Pottsville, Pa., to Philadelphia, a distance of 93 miles. By its subsequent extensions and branches and by the acquirement of the control of other roads the company now operates 2 210 miles of railroad, and, excluding the Atlantic City Railroad in southern New Jersey, it has 2 094 miles of railroad terminating in Philadelphia. Its lines extend through or into 18 counties of Pennsylvania which have an aggregate area of 9 805 square miles and a population of 2 400 000.

At Bound Brook, N. J., connection is made with the Central Railroad of New Jersey, furnishing a route to New York City; at Bethlehem, Pa., it joins the Lehigh Valley Railroad and provides direct communication between Philadelphia and the Lehigh and Wyoming Valleys, and also a route to Buffalo and the Great Lakes; at Williamsport, Pa., it unites with railroads leading into the bituminous coal fields of northern and western Pennsylvania; and by its Lebanon Valley division and branches, passing through the rich country of Lancaster, it reaches Harrisburg, the capital of the state, and, after crossing the Susquehanna River, it penetrates the Cumberland Valley toward Gettysburg and goes on to the valley of the Potomac. At Philadelphia a connection is established with the Baltimore and Ohio Railroad, furnishing communication with Baltimore, Washington and the South. This company had four passenger terminals in Philadelphia, two of them legacies from leased lines, all located in inconvenient points far removed from business centers, but by the construction of its terminal road it has now established its main passenger station in the heart of the city and within two blocks of the City Hall.

In order to show justification for the erection of such a terminal as has been built, it may be stated that in 1891 the number of passengers carried by the Philadelphia and Reading Railroad was over 18 000 000, and in 1893 there were over 20 700 000, of which about 10 000 000 arrived at or departed from Philadelphia. About 75% of the latter might be classed as suburban; that is, comprised within a radius of 20 miles from the city. At the present time 294 passenger trains arrive at and depart from the terminal station daily.

The project involved not only the building of a station, but the construction of lines of railroad connecting the old terminals together.

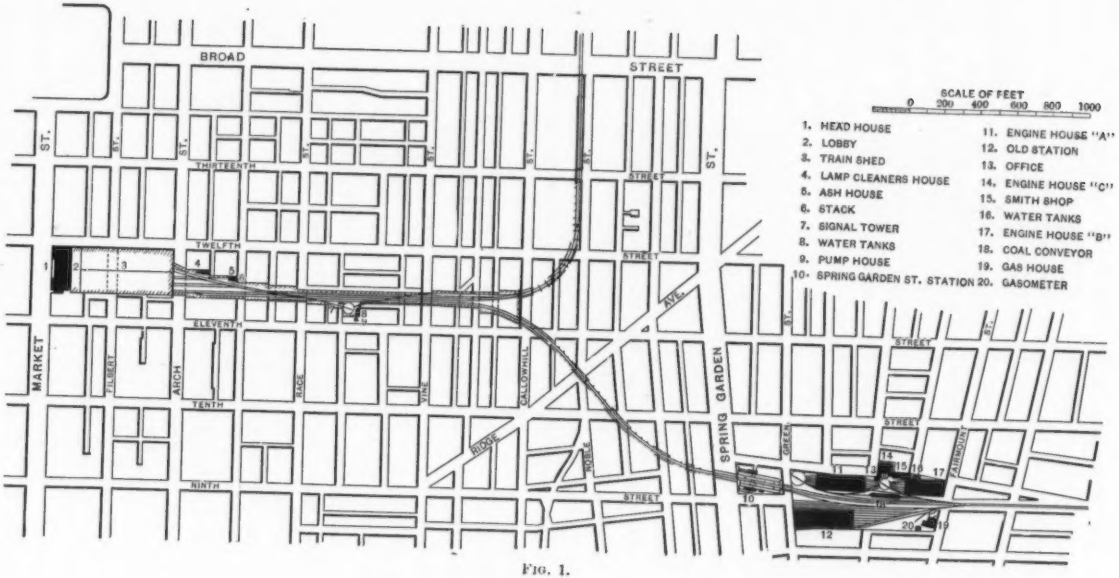

BROAD
STREET
MARKET
ST.
THIRTEENTH
TWELFTH
ELEVENTH
TENTH
NINTH
FILBERT
ARCH
RACE
VINE
CALLOWHILL
SPRING GARDEN
GREEN
FAIRMOUNT
AVE.
SCALE OF FEET
0 200 400 600 800 1000
1. HEAD HOUSE
2. LOBBY
3. TRAIN SHED
4. LAMP CLEANERS HOUSE
5. ASH HOUSE
6. STACK
7. SIGNAL TOWER
8. WATER TANKS
9. PUMP HOUSE
10. SPRING GARDEN ST. STATION
11. ENGINE HOUSE "A"
12. OLD STATION
13. OFFICE
14. ENGINE HOUSE "C"
15. SMITH SHOP
16. WATER TANKS
17. ENGINE HOUSE "B"
18. COAL CONVEYOR
19. GAS HOUSE
20. GASOMETER

FIG. 1.

The existing connections in the outskirts of the city made it possible to do this by bringing together two roads, the main line of the Philadelphia and Reading Railroad on Pennsylvania Avenue, with its terminal at Broad and Callowhill Streets, and the Germantown and Norristown Railroad, with its station at Ninth and Green Streets. From these two lines the new terminal railroad was built.

The Terminal Railroad.—The lines of track forming the Terminal Railroad and connecting the station with the previously existing roads consist of a main line and two branches. The main line starts out from the station with 13 tracks which reduce in a distance of 350 ft. to five. It then continues northward to Wood Street, a distance of about 1 650 ft. from the end of the train-shed, where the five tracks separate into two branches of two tracks each. One of these branches turns westward and at a further distance of about 1 600 ft. connects with the main line of the Philadelphia and Reading Railroad at Broad and Noble Streets. The other branch takes a northeasterly direction and about 2 100 ft. beyond Wood Street joins the Germantown and Norristown branch at Ninth and Green Streets.

Active measures were taken in the spring of 1888 to commence the work on the Terminal Railroad, but the natural conservatism of the Quaker City, combined with opposition from rival railroad interests, caused a long delay, and it was not until December 26th, 1890, that a city ordinance was secured granting municipal consent for the construction of the line. The first contract for the road was executed on May 15th, 1891.

The whole of the railroad is built on private property acquired by the company, and from which existing buildings had to be removed. In some cases annoying delays occurred on account of litigation in securing the ground. Fig. 1 shows a general map of the road.

The mileage of the road is as follows:

Miles of first track	1.317
" second track	1.307
" third track	0.467
" fourth track	0.544
" yard track and sidings	2.998
Total mileage operated (all tracks)	6.633

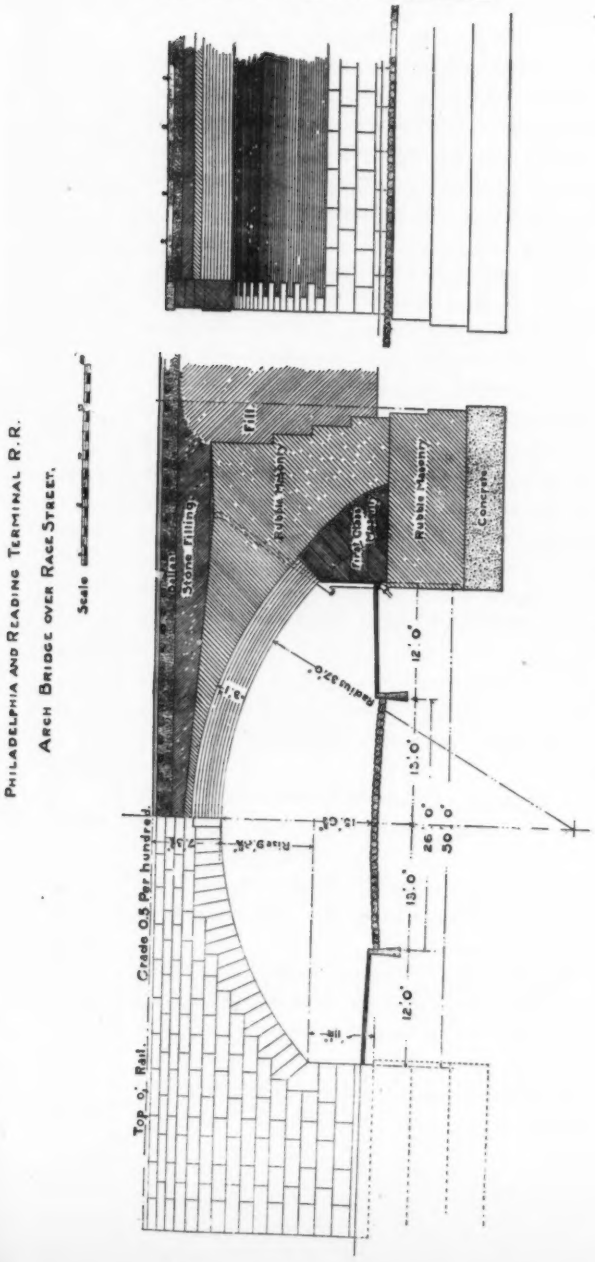

PHILADELPHIA AND READING TERMINAL R.R.
ARCH BRIDGE OVER RACE STREET.
Scale
Fill
Stone filling
Rubble masonry
Concrete
Radius 37.0'
Grade 0.5 Per hundred.
Top of Rail.
12.0'
13.0'
26.0'
50.0'

FIG. 2.

The line crosses Arch Street by a plate girder bridge of 72 ft. clear span; thence, between Arch and Cherry Streets, it is carried by a wrought-iron column and plate girder construction over the power-house of the station, and from Cherry to Callowhill Streets, about 1 520 ft. in length, it is laid on a solid roadbed filled in behind retaining walls of stone masonry.

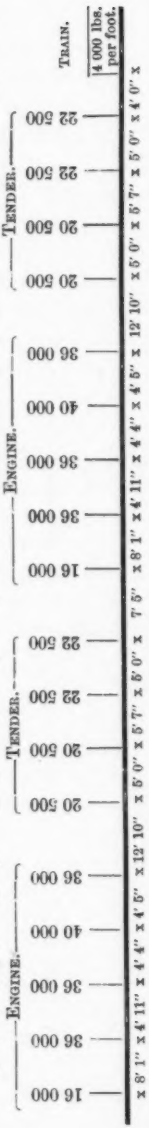
The street bridges on this part of the line are brick arches with stone-face walls. There are two bridges of 50 ft. clear span between skew-backs, two of 40 ft., two of 30 ft., and one of 20 ft., making a total of 260 ft. Fig. 2 shows the bridge over Race Street, and the other bridges are of similar construction. Beyond the south line of Callowhill Street, which is about 250 ft. north of the point of separation of the branch lines, the two branches are carried by wrought-iron elevated girder construction, the branch to Ninth and Green Streets being of the type shown by Fig. 3, with wrought-iron columns, and that to Broad and Noble Streets having stone piers for most of it, although a small portion is also supported by iron columns.

Spring Garden Street is crossed by a skew, pin-connected, open through truss bridge of about 126 ft. 2½ ins. clear span. The other street bridges are plate girders.

The total length of iron elevated structure on both branches, including the bridges over streets, is 2 665$\frac{1}{10}$ ft.

This work was designed to carry two loads, one on each track, trains headed in the same direction on adjacent tracks, as follows:

Two typical engines coupled, weighing with tender 125 tons each, distributed as shown in the diagram and connected with a train weighing 4 000 lbs. per lineal foot of track. The specifications were in accordance with the standard of Messrs. Wilson Brothers & Company, of date April 11th, 1891.



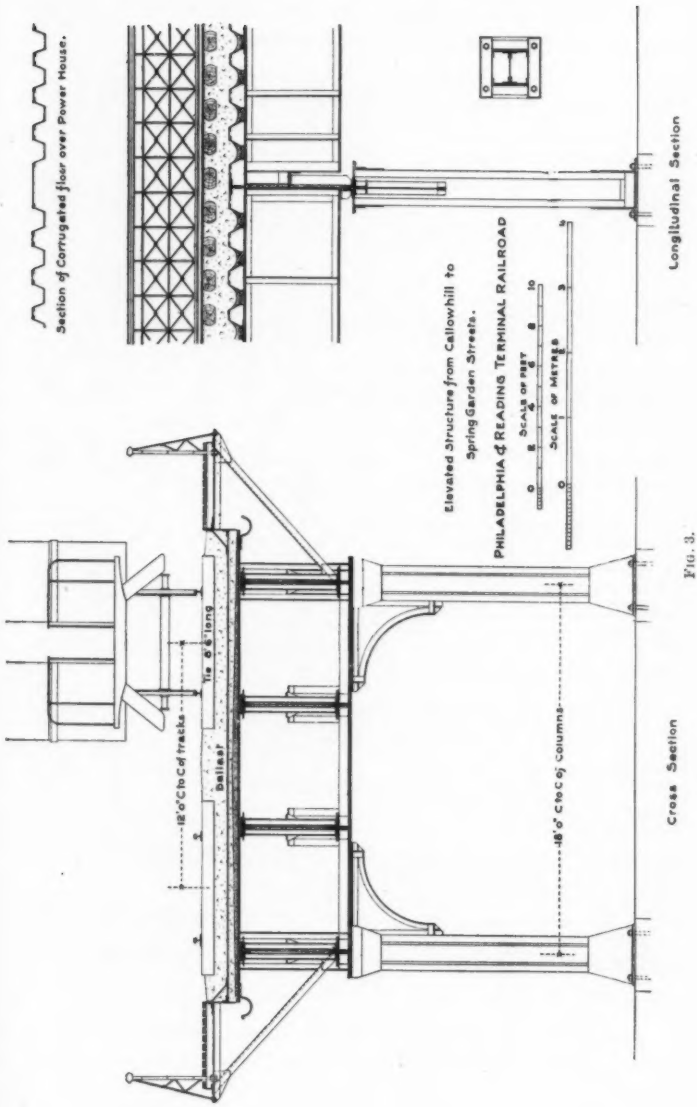

Section of Corrugated floor over Power House.
Elevated Structure from Callowhill to Spring Garden Streets.
PHILADELPHIA & READING TERMINAL RAILROAD
SCALE OF FEET
SCALE OF METRES
Longitudinal Section
Cross Section
18'0" C to C of tracks
Ballast
Ties 8'6" long
18'0" C to C of columns

FIG. 3.

The various contracts made for the station are given as follows, and show the order and rate of progress of the work :

	Contractor.	Date.
Foundations of train-shed	Charles McCaul	July 9, 1891
Structural iron work of train-shed from foundation masonry up to and including track floor	A. & P. Roberts & Co	Aug. 17, 1891
Granite work of train-shed	Charles McCaul	Sept. 5, 1891
Train-shed roof	Phœnix Bridge Co	Oct. 12, 1891
Train-shed, work up to and including second floor	Charles McCaul	Oct. 20, 1891
Train-shed, structural iron work between north line of Filbert Street and north line of headhouse	A. & P. Roberts & Co	Dec. 29, 1891
Work between Arch and Cherry Streets, iron work	Cofrode & Saylor	Dec. 29, 1891
Floors and paving, granolithic curb	Vulcanite Paving Co	Dec. 29, 1891
Granite work of head-house	Charles McCaul	Jan. 28, 1892
Completion of train-shed and market-house	" "	Feb. 2, 1892
Iron work for stalls and market-house	Wharton Railroad Switch Co	Mar. 2, 1892
Portion between Arch and Cherry Streets	Charles McCaul	Mar. 16, 1892
Wood work for stalls in market-house	" "	Mar. 25, 1892
Work in head-house up to second-floor level	" "	Mar. 30, 1892
Boilers	Edge Moor Iron Co	Apr. 20, 1892
Elevators	Stokes & Parrish Elevator Co	Apr. 21, 1892
Terra cotta work	Perth Amboy Terra Cotta Co	Apr. 25, 1892
Marble work for fish stands	Atkinson & Myhlertz	Apr. 28, 1892
Face brick	Perth Amboy Terra Cotta Co	June 30, 1892
Sheet metal work, copper cornice, etc	J. S. Thorn	July 18, 1892
Refrigerating and cold storage plant	Pennsylvania Iron Works Co.	July 30, 1892
Completion of head-house	Charles McCaul	Aug. 19, 1892
Arc electric lighting	Western Electric Co	Nov. 4, 1892
Burglar-proof vault	Damon Safe and Iron Works Co	Sept. 1, 1892
Floors in restaurant, kitchen, express office and driveway	Vulcanite Paving Co	Nov. 9, 1892
Heating head-house, etc	Onderdonk Heating and Ventilating Co	Nov. 12, 1892
Temporary waiting-rooms	Charles McCaul	Jan. 3, 1893
Ventilating plant for head-house	Onderdonk Heating and Ventilating Co	Jan. 31, 1893
Water supply and drainage, furniture fittings of restaurant-kitchen, bakery, etc	Charles McCaul	Feb. 1, 1893
Wiring power-house for incandescent electric lighting	M. R. Muckle, Jr., & Co	Feb. 7, 1893
Track signs	D. A. Woelpper & Co	Feb. 8, 1893
Gate signs	Albanus L. Smith & Co	Feb. 8, 1893
Three Westinghouse automatic compound engines for power-house	M. R. Muckle, Jr., & Co	Jan. 31, 1893
Cold storage-rooms	Pennsylvania Iron Works Co	Apr. 13, 1893
Direct current incandescent electric lighting	M. R. Muckle, Jr., & Co	June 5, 1893
Wire screens and guards for floor lights, etc	DeWitt Wire Cloth Co	July 12, 1893
Overhead tracking, switches, etc., in exterior corridors and elevators in cold storage vaults of terminal market, etc	J. W. Moyer	July 15, 1893
Tunnel enclosures, wood and glass partitions, iron steps and floors, coal-bin doors and brass railings, etc., in power-house and cold storage vaults	Charles McCaul	July 20, 1893

In describing the station building the various portions of it are considered separately in detail, arranged in such order as has seemed most desirable.

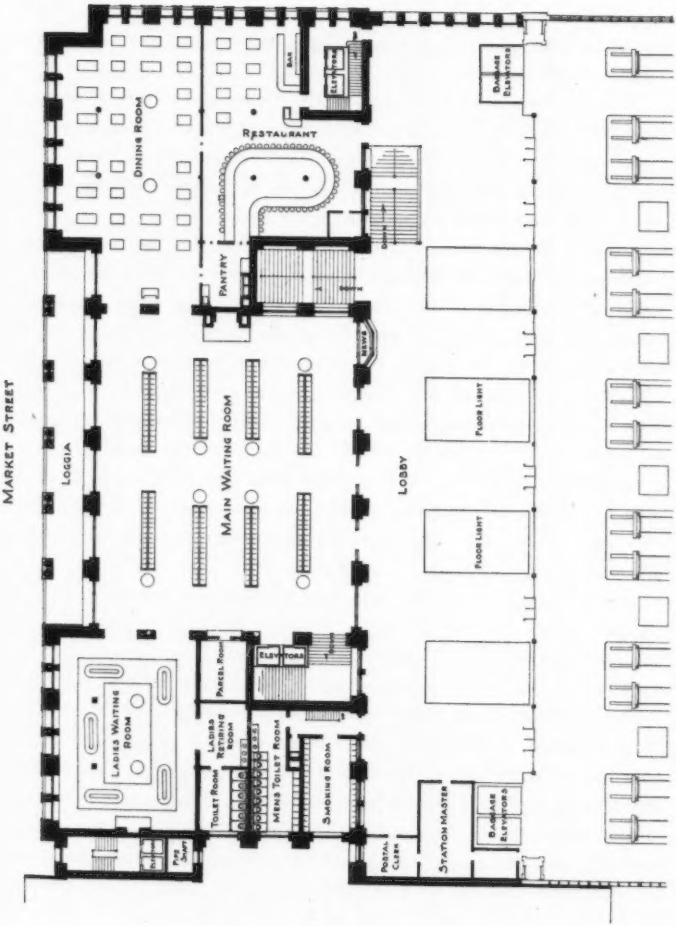

MARKET STREET
LOGGIA
DINING ROOM
RESTAURANT
PANTRY
MAIN WAITING ROOM
LOBBY
FLOOR LIGHT
FLOOR LIGHT
LADIES WAITING ROOM
LADIES RETIRING ROOM
TOILET ROOM
PARCEL ROOM
ELEVATORS
MENS TOILET ROOM
SMOKING ROOM
POSTAL CLERK
STATION MASTER
BAGGAGE ELEVATORS
BAGGAGE ELEVATORS

FIG. 4.

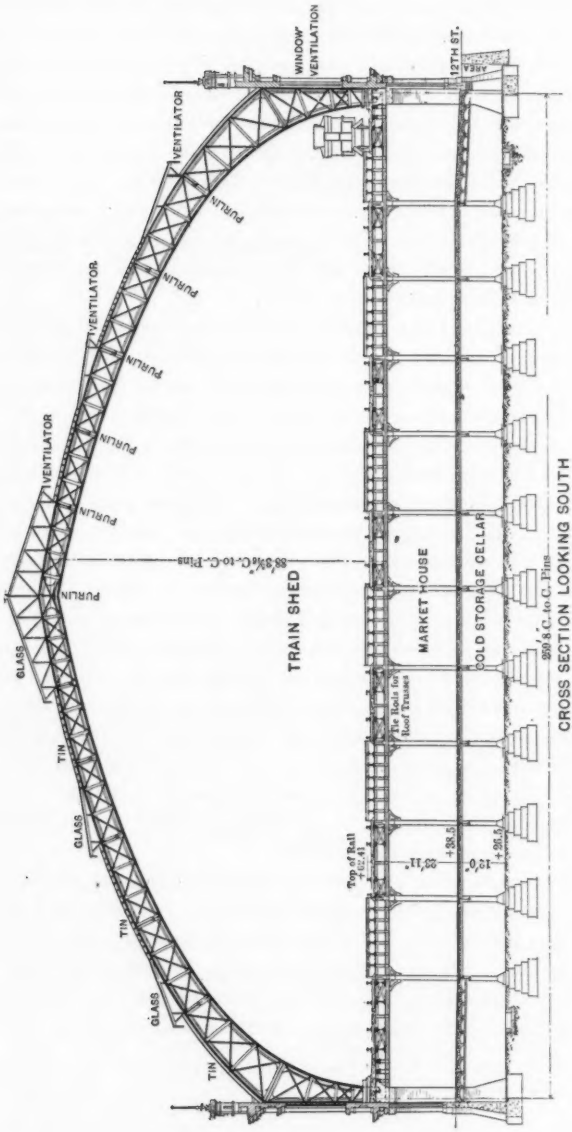
The only steel used in the elevated railroad work was in the lower chord links of the Spring Garden Street Bridge and in the corrugated floor over the power-house. Acid open-hearth steel was allowed, having an ultimate strength of 62 000 to 68 000 lbs. per square inch, an elastic limit of one-half the ultimate, and a minimum stretch in a length of 8 ins. of 20 per cent.

A 60-ft. turn-table is placed on the terminal line about 1 000 ft. north of Cherry Street and two tables of the same size at Ninth and Green Streets, where are also located three brick engine-houses, covering a combined area of about 46 000 sq. ft., capable of housing 40 engines and also providing a small repair shop.

There is also at this point a locomotive supply station, designed and built by the C. W. Hunt Company, of New York, in which four locomotives can simultaneously take coal, sand and water, and dump ashes. All solid material is handled by the Hunt conveyor. Coal and sand are thrown into pockets below the tracks from drop-bottom cars, and are then conveyed for a vertical height of 69 ft. to storage bins, from which they are drawn for supply. Locomotives discharge their ashes also into receptacles below, and the conveyor carries them to a bin in the upper part of the house, from which they may be filled into cars for removal. The capacity of the conveyor is such that coal may be stored at 60 tons, sand at 80 tons, and ashes at 40 tons per hour.

The terminal work also comprised an elevated station at Spring Garden Street, shown on Fig. 1, to serve the local traffic formerly accommodated by the old station at Ninth and Green Streets.

The site selected for the terminal station was on the northeast corner of Market and 12th Streets, with a frontage on the south on Market Street of 266 ft. 10¾ ins., and on the west extending back on 12th Street 662 ft. 11⅝ ins. to Arch Street, the north front on the latter street being 276 ft. 7¼ ins. The width of Market Street is 100 ft., that of 12th Street 50 ft., and Arch Street 72 ft. The property was intersected by two cross streets parallel to Market Street, Filbert Street 51 ft. wide and 307 ft. 1⅝ ins. north of Market Street, and Cuthbert Street 30 ft. wide and 136 ft. 4¾ ins. north of Filbert Street. Cuthbert Street was abandoned and closed, but it was found necessary to retain Filbert Street. The property was also accessible by another street, Hunter Street, 30 ft. wide, extending on the east side from 11th Street



CROSS SECTION LOOKING SOUTH

FIG. 5

at a point 181 ft. ⅜ in. north of Market Street, but not passing through it. The curb elevations on the street, referred to city datum,* vary from + 36.16 to + 38.09, and the elevation for the top of rail in the station was fixed at + 62.416, with level branches entering the station from the north and crossing Arch Street by a bridge. These fundamental data determined the arrangement of the station and fixed the location of the head-house, facing on Market Street and extending back only so far as necessary to provide the requisite accommodation for waiting-rooms, offices, etc., as much space as possible being allowed between it and Arch Street for the train-shed, with a passenger corridor between it and the head-house.

The elevation of the railway tracks being about 25 ft. above the street grades, required the principal floor of the station to be placed in the second story of the head-house, the first or ground floor being available for entrance, waiting-rooms, ticket offices, baggage-rooms, etc. It having been decided to establish the general offices of the company at the station, certain portions of the first floor, not otherwise required, and all of the floors above the second story, could be appropriated for this purpose. It is evident that there still remained unappropriated a vast extent of valuable space on the ground floor under the train-shed, and the fact that the property between Market and Filbert Streets was occupied by two important market houses, controlling an excellent and well-established business, which were to be demolished for the erection of the station, suggested the idea of constructing a new market house on the ground floor under the train-shed and of transferring the valuable business of the old markets to it. It was also decided that cellars could be built under the market for cold storage, and that such an arrangement would possess particular advantage in allowing a ready application of refrigeration for the preservation of market supplies, thereby dispensing with the use of ice.

A large space under the entrance tracks on the north side of Arch Street, having a frontage of 149 ft. 2⅜ ins. and extending back 285 ft. 7¼ ins. to Cherry Street, was found available for the operating plant of the terminal. By the continuation of Hunter Street through the station as a private way, a space was secured for the delivery of baggage and for use as a cab-stand. These are the principal features

* City datum is 8.732 ft. above the level of the Atlantic Ocean at Raritan Bay and 2.24 ft. above mean high tide at Philadelphia.

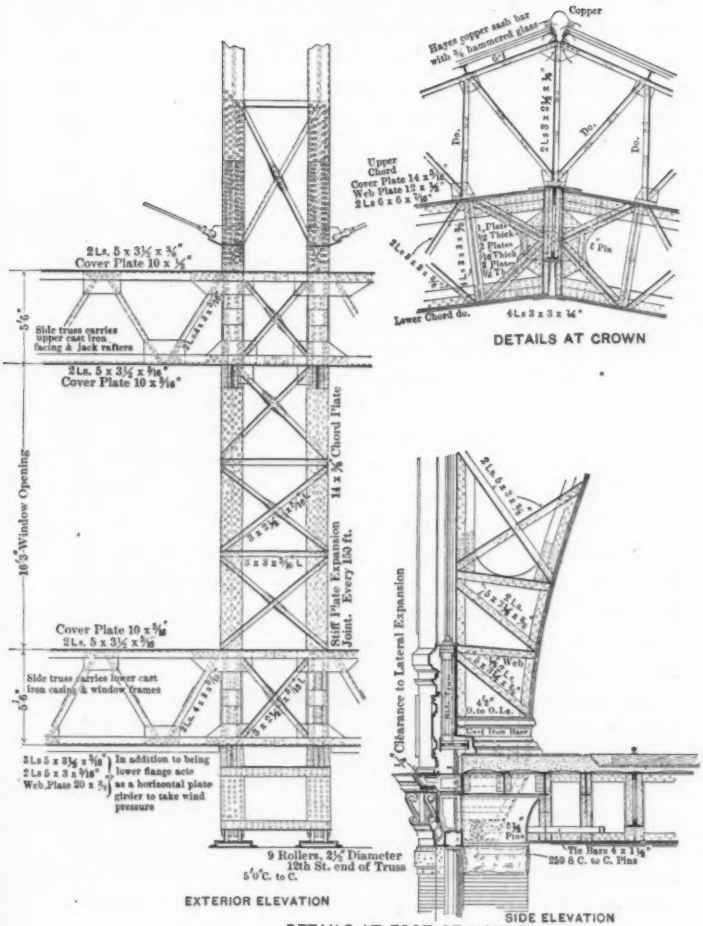
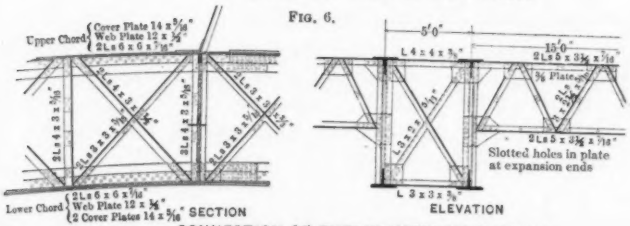

Copper
Hayes copper sash bar with ⅜ hammered glass
Upper Chord
Cover Plate 14 x 5/16"
Web Plate 12 x ½"
2 Ls 6 x 6 x 5/16"
Lower Chord do.
4 Ls 3 x 3 x ¼"
DETAILS AT CROWN
2 Ls. 5 x 3½ x ¾"
Cover Plate 10 x ½"
Side truss carries upper cast iron facing & Jack rafters
2 Ls. 5 x 3½ x 5/16"
Cover Plate 10 x 5/16"
16'3" Window Opening
14 x ⅜ Chord Plate
Stiff Plate Expansion Joint. Every 150 ft.
Cover Plate 10 x 5/16"
2 Ls. 5 x 3½ x 5/16
Side truss carries lower cast iron casing & window frames
3 Ls 5 x 3¼ x 5/16"
2 Ls 6 x 3 x 5/16"
Web Plate 20 x 5/16"
In addition to being lower flange acts as a horizontal plate girder to take wind pressure
9 Rollers, 2½" Diameter
12th St. end of Truss
5'0"C. to C.
EXTERIOR ELEVATION
¼" Clearance to Lateral Expansion
4½" O. to O. Ls.
Steel from Barr
2½" Pins
Tie Bars 4 x 1¼"
259 8 C. to C. Pins
SIDE ELEVATION
DETAILS AT FOOT OF MAIN TRUSS

FIG. 6.


Upper Chord
Cover Plate 14 x 5/16"
Web Plate 12 x ½"
2 Ls 6 x 6 x 5/16"
Lower Chord
2 Ls 6 x 6 x 5/16"
Web Plate 12 x ½"
2 Cover Plates 14 x 5/16"
SECTION
5'0"
15'0"
2 Ls 5 x 3½ x 5/16"
⅝ Plate
2 Ls 5 x 3½ x 5/16"
Slotted holes in plate at expansion ends
ELEVATION

CONNECTION OF PURLIN WITH MAIN TRUSS

FIG. 7.

which governed the arrangement of the plans for the station. Possession was obtained of that portion of the property between Filbert and Arch Streets in advance of that south of Filbert Street, and the necessity of pushing the work to completion as rapidly as possible, together with the great advantage that would accrue from having the new market house built before the old one was demolished, decided that the work on the station should be executed by successive steps in a series of contracts, beginning at Arch Street and working south, the head-house being the last portion of the structure completed.

The various complications arising from these circumstances and also incident to the construction of a railroad through a solidly built-up city made the time required for the entire work longer than it would have been had the ground been cleared in advance. The work was, however, successfully carried out in accordance with the programme adopted, the new market house was built, the tracks for the train-shed laid and a water-proof floor put down; the occupants of the old markets were transferred without interruption to business, and the construction of the head-house proceeded with on the old site. The tracks and train-shed were opened for travel (using temporary passenger rooms) on January 29th, 1893, and the permanent passenger rooms in the head-house were completed and put into use on October 16th of the same year.

The Head-House.—A number of preliminary sketches and designs were prepared by the engineers and architects, Messrs. Wilson Brothers & Co., and after their careful consideration it was decided to adopt the Italian renaissance as the type of architecture for the structure. In reaching this decision, the president of the company availed himself of the services of Mr. Francis H. Kimball, of New York (who was at that time doing certain work for the Philadelphia and Reading Railroad Company), as a "consulting architect on the exterior ornamentation." Mr. Kimball also made some preliminary sketches and drawings for the exterior treatment, acting in unison with Messrs. Wilson Brothers & Co. in this matter, and the final design for the exterior of the head-house as prepared by that firm and adopted was the resultant of such consultation and Mr. Kimball's suggestions. All of the general drawings and the scale details of the ornamentation were prepared by Messrs. Wilson Brothers & Co.; the full-size drawings of the terra

cotta details and the inspection of the terra cotta at Perth Amboy were done by Mr. Kimball.

The face of the head-house is set back 6 ft. $6\frac{1}{8}$ ins. from the building line of Market Street, so as to increase the width of the pavement in front, and the depth of the structure on Twelfth Street is 100 ft. 6 ins. On the first floor, back of the head-house proper, are the baggage-rooms, which occupy an additional depth of 73 ft. $11\frac{3}{8}$ ins., and cover the space all the way to an open passage through the station from Hunter Street to Twelfth Street, intended for cab service and access to baggage-rooms by wagons.

In designing a building of this kind and extent, the proper mode of procedure is first to determine a certain unit of square or rectangle by which the ground plan can be divided up into a number of parts, and to the intersecting or division lines of which the columns, walls, partitions, etc., may be made to conform, although it is possible that in special cases some variation from these lines may be necessary. In the present case the key to the arrangement of plans is a unit rectangle of 16 ft. north and south by 20 ft. east and west as may be seen by reference to the drawings.

The building consists of a cellar, basement, and practically eight stories, the second and third stories being merged into one high story in that portion of the second floor occupied by waiting-rooms. The central portion of the first story is appropriated to passenger entrances, ticket offices and waiting-rooms, while the east and west portions are used for offices; and as these parts do not require as high ceilings as the waiting-rooms, the floors are raised, allowing basements to be placed under them.

The elevation of first floor in central portion is.....	+ 39.75
" " " at east and west ends is.....	+ 44
" " basement floor is.....	+ 32.5

A cellar is constructed under the whole of the head-house, the elevation of the floor being + 22.5, thus giving under the central part of the building a height of 17 ft. 3 ins. from floor to floor, and 10 ft. under the basement ends.

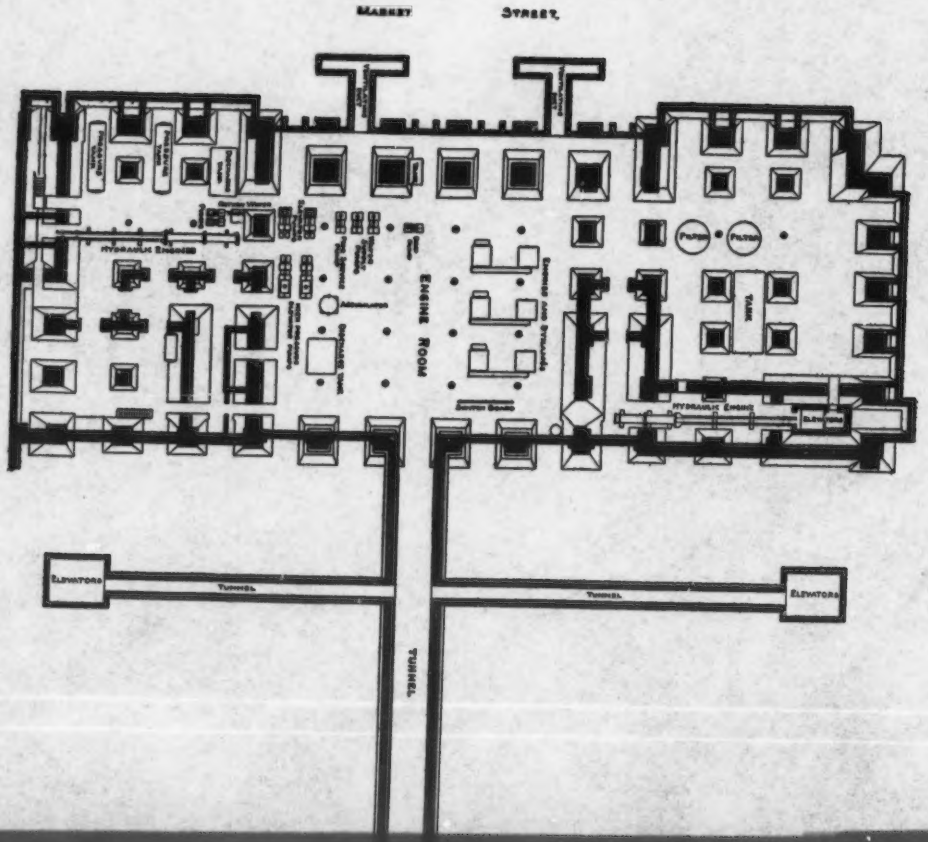
The heights of the several stories of the building, measured from floor to floor, are as follows:

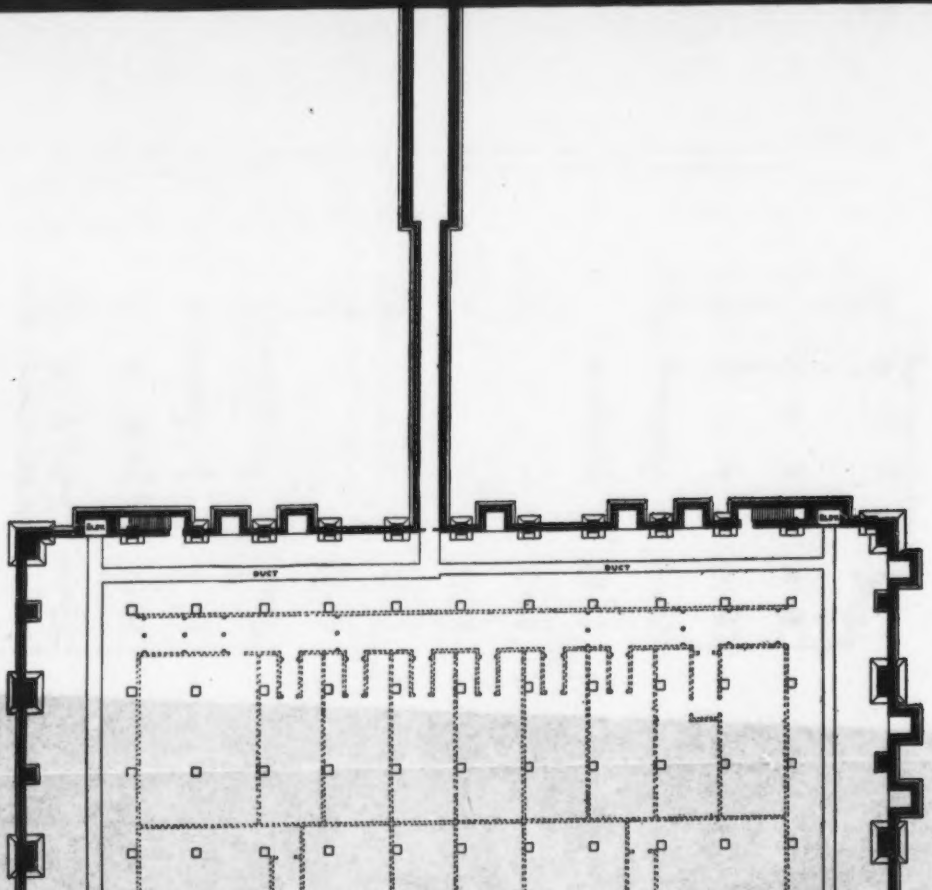
	Feet.	Inches.
Cellar to basement	10	0
" " first floor where no basement exists	17	3
Basement to first floor over basement	11	6
First floor to second floor where no basement exists	23	3
First floor to second floor where basements exist	19	0
Second floor to entresol (or half-story)	19	0
Entresol to third floor	16	0
Second floor to third floor, where no entresol exists	35	0
Third to fourth floors	16	0
Fourth to fifth "	13	6
Fifth to sixth "	13	6
Sixth to seventh "	13	6
Seventh to attic "	13	6
Attic floor to apex of roof	14	0½
Total height, cellar floor to apex of roof	169	6½

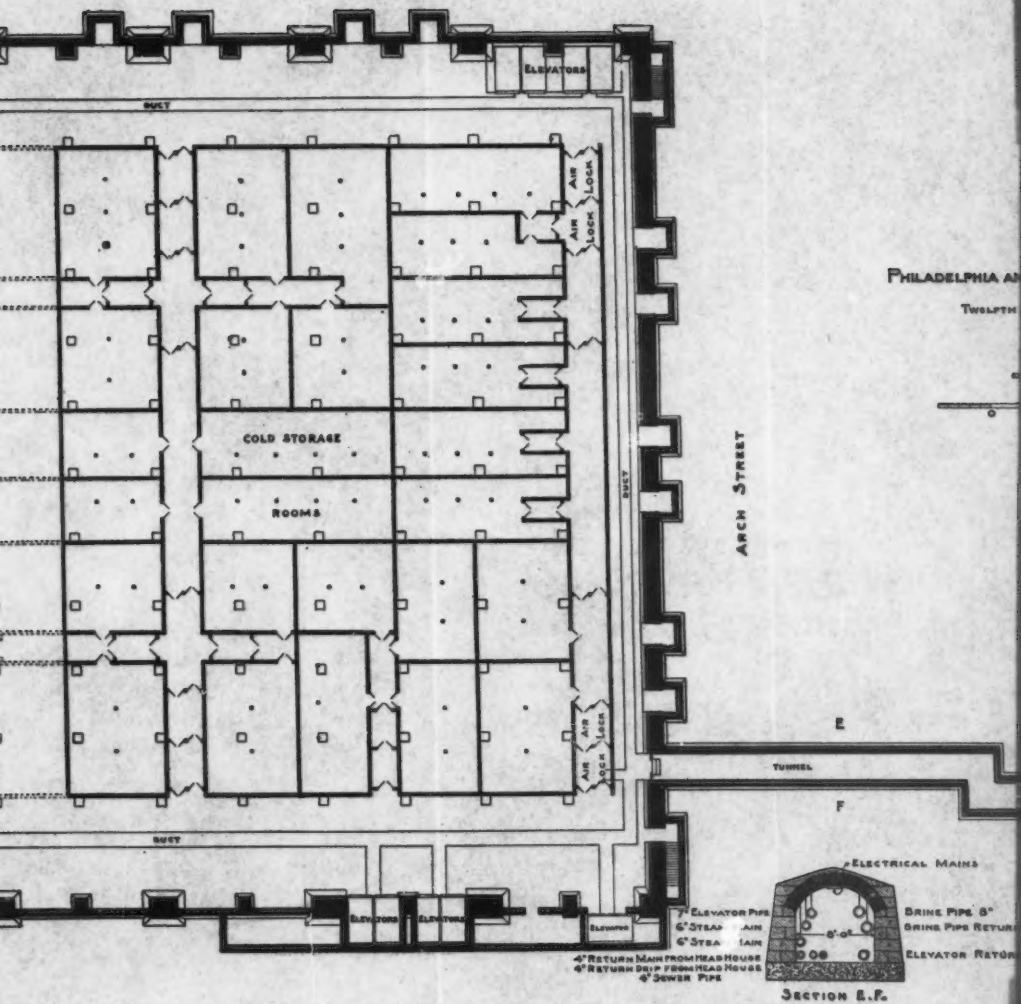
The exterior faces of the building on the street fronts are constructed of pink eastern granite for the height of the basement and first story, and above that of pink brick and cream-white terra cotta. For facing the rear elevation and the light well, a pale red brick, known as telephone brick, is used. The upper part of the cornice of the building is of copper.

The construction of the head-house, from the foundation up to and including the second floor, is fireproof, having wrought and cast-iron columns, wrought-iron or steel beams, and brick floors. For a portion of the work Gustavino flooring is used. Above the second floor a slow-burning construction has been adopted, consisting of iron or steel columns and beams, with heavy plank floors; the columns, beams and undersides of floors being protected with mackite plasterboards on which the finishing plaster is laid. The partitions are also constructed of solid mackite, 6 ins. in thickness, a material that, while very light in weight, is, from its composition, principally plaster of paris, asbestos fiber, and encased reeds, unexcelled in its fire-resisting properties. The roof is of the same general construction as the upper floors of the building, and is covered with tin.

While wrought-iron columns are used to support the main girders which span the waiting-rooms, yet the construction of the exterior


MARKET STREET
HYDRAULIC ENGINES
ENGINE ROOM
Pumps
Pumps
TANK
HYDRAULIC ENGINES
ELEVATORS
TUNNEL
TUNNEL
ELEVATORS
TUNNEL


DUCT
DUCT


ELEVATORS
DUCT
AIR LOCK
AIR LOCK
COLD STORAGE
ROOMS
DUCT
ARCH STREET
PHILADELPHIA
TWELFTH
E
TUNNEL
F
DUCT
ELECTRICAL MAINS
7" ELEVATOR PIPE
BRINE PIPE 8"
6'-0"
4" RETURN MAIN FROM MEAD HOUSE
4" RETURN DRIP FROM MEAD HOUSE
4" SEWER PIPE
SECTION E.F.

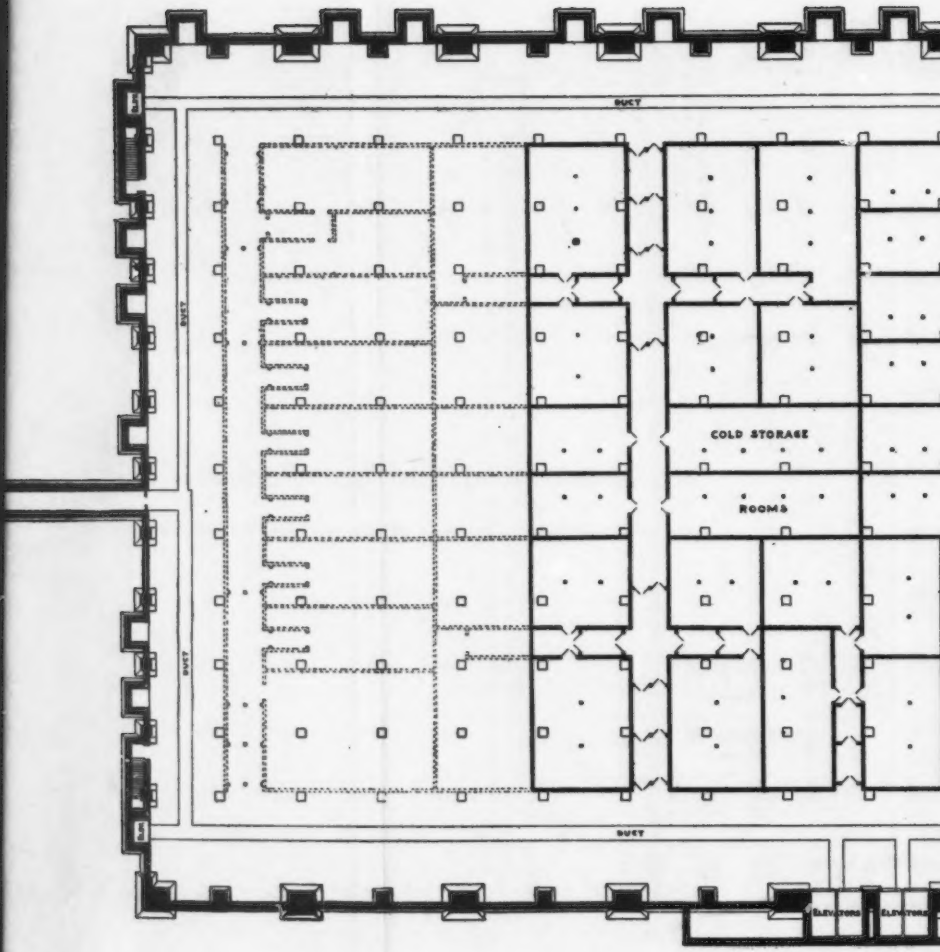
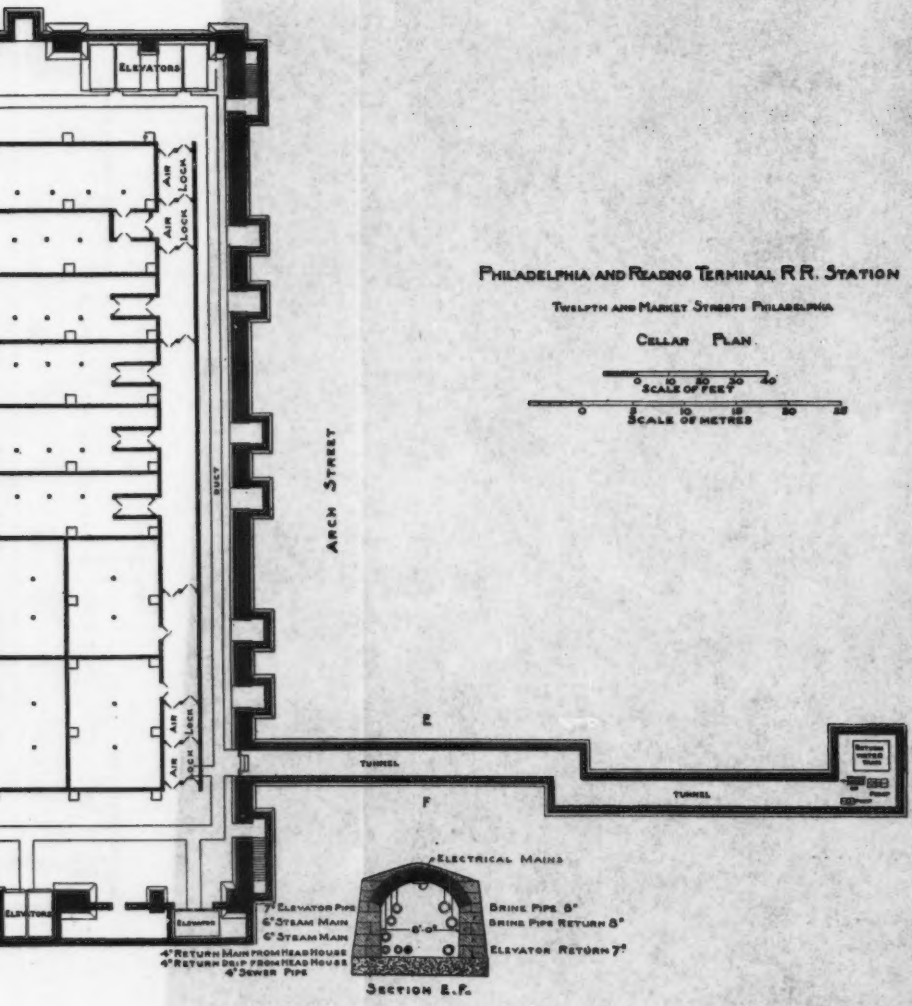

DUCT
DUCT
DUCT
DUCT
COLD STORAGE
ROOMS
ELEVATORS
ELEVATORS

PLATE I.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXXIV, No. 767.
WILSON ON READING TERMINAL.



PHILADELPHIA AND READING TERMINAL R.R. STATION

TWELFTH AND MARKET STREETS PHILADELPHIA

CELLAR PLAN

walls of the building is not based on a skeleton iron or steel system of building, and columns are not used in these walls except for the support of the special main girders above mentioned. The thickness of exterior wall on Twelfth Street, which represents an average for the building, is as follows:

	Feet.	Inches.
Concrete foundation	16	
Base of masonry resting on concrete	14	
First story	5	6
Second story to third floor	5	
Third and fourth stories	4	
Fifth and sixth stories	3	6
Seventh story and attic	3	

It must be observed that the walls are merely a series of piers, the windows being deeply recessed for architectural effect, and the curtains under the windows very much reduced. This accounts for what might otherwise appear to be an excessive thickness.

Cellar.—The cellar provides ample room for all of the operating machinery needed in this part of the building, and a main tunnel, running north to the cold storage cellar, and from that continuing under Arch Street, connects it with the power plant which is placed on the property north of that street (see Plate I). This tunnel has a clear cross-section of 11 ft. width by 11 ft. height to crown of arch, as far as Hunter Street, and 6 ft. 2 ins. width by 7 ft. 1 in. height beyond that point to the cellar of the market house, which it enters with its bottom 2 ft. below the cellar floor. There is no basement or cellar under the baggage-rooms, but cross-tunnels 4 ft. wide by 6 ft. clear height run from the main tunnel to the locations of the elevators in these rooms. The cellars have cement floors.

Basements.—The basements under the east and west ends of the building are each divided into three rooms, with entrances from the street by steps down from the pavement, so that they may be rented as stores. The rooms average 750 to 1 000 sq. ft. of floor surface each, and they have wooden floors. Convenient lavatory and sanitary arrangements are provided.

First Floor.—There are two entrances on the first floor communicating with the office floors in the upper part of the building, one on Market Street and one on Twelfth Street, each provided with a stair-

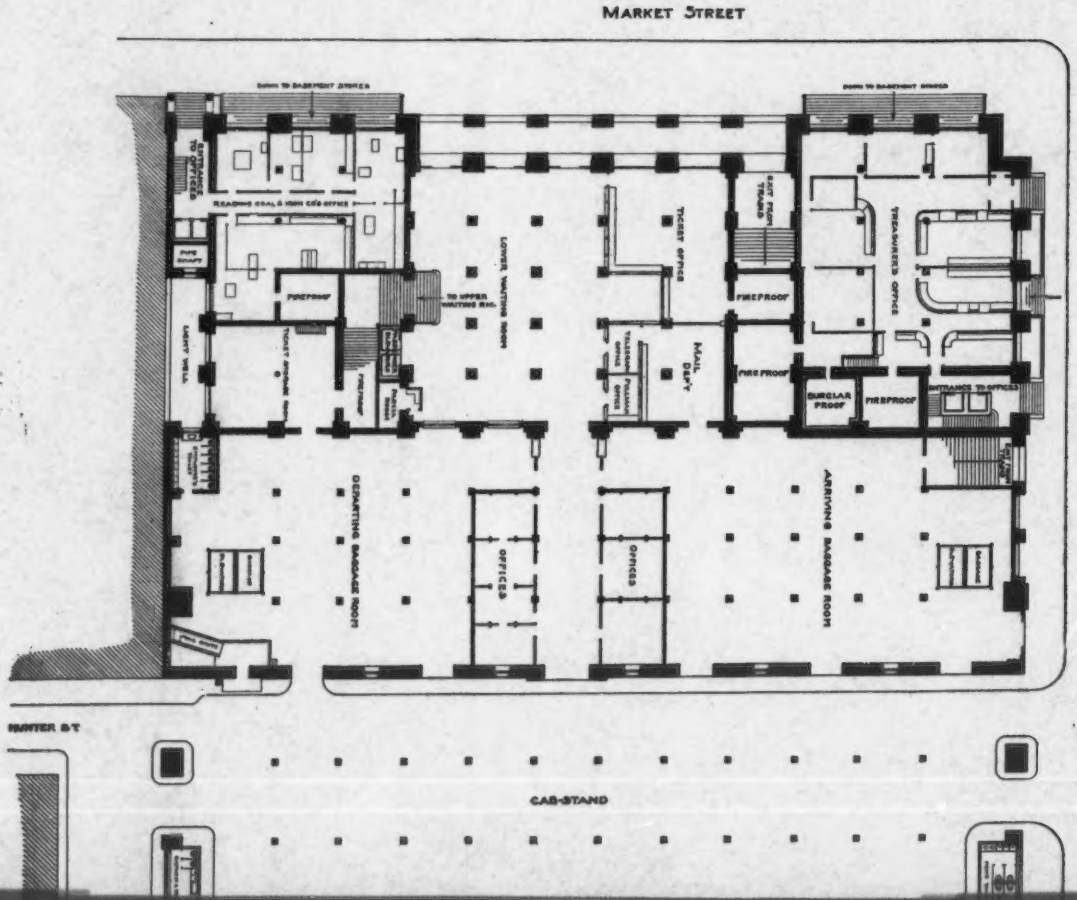
way and two elevators. The main passenger entrance is in the center of the Market Street front, and exits from the second floor passenger corridor are provided by stairways on Market and Twelfth Streets.

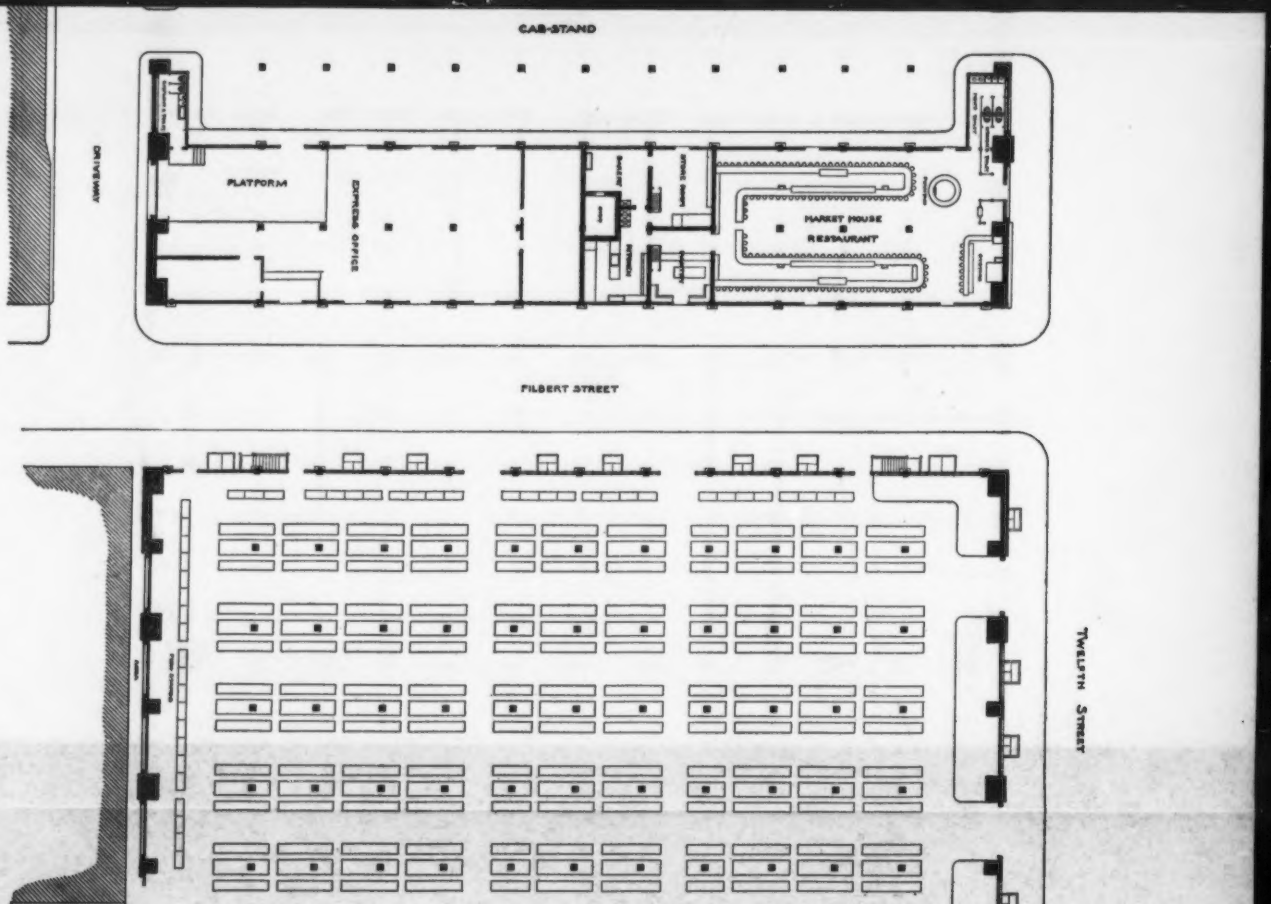
The central part of this floor is occupied by the waiting-room, ticket office, sub-post office, Pullman and telegraph offices; the western part, at the corner of Twelfth and Market Streets, by the Treasurer's office, and the eastern portion, fronting on Market Street, by the Coal and Iron Department, back of which are the ticket storage-rooms. To the rear of the building are the baggage-rooms with a corridor 20 ft. in width between them, running from the waiting-room to the Hunter Street extension cab-stand. On each side of this corridor are arranged a series of offices, cut off from the baggage-rooms and averaging 240 to 400 sq. ft. of floor area each, those on the right being intended for the medical, missing freight and baggage departments, while those on the left are for the company's mail and advertisement inspectors (see Plate II).

Two large passenger elevators and a stairway communicate from the first to second story waiting-rooms, and each baggage-room has two elevators of sufficient size to carry baggage trucks to the train-shed floor. The Treasurer's office, the ticket office and the Coal and Iron Department each have ample fire and burglar-proof vaults. The sub-post office has a mail chute from the second floor so as to afford facilities to passengers for mailing letters. The floors of the main waiting-room and baggage-rooms are of cement, and all the other rooms, used as offices, have wooden floors. At the east end of the building is a ventilation and light area 45 by 12 ft., and a shaft about 7 ft. 6 ins. by 10 ft. 8½ ins. for carrying supply pipes, steam pipes, etc., to the top of the building.

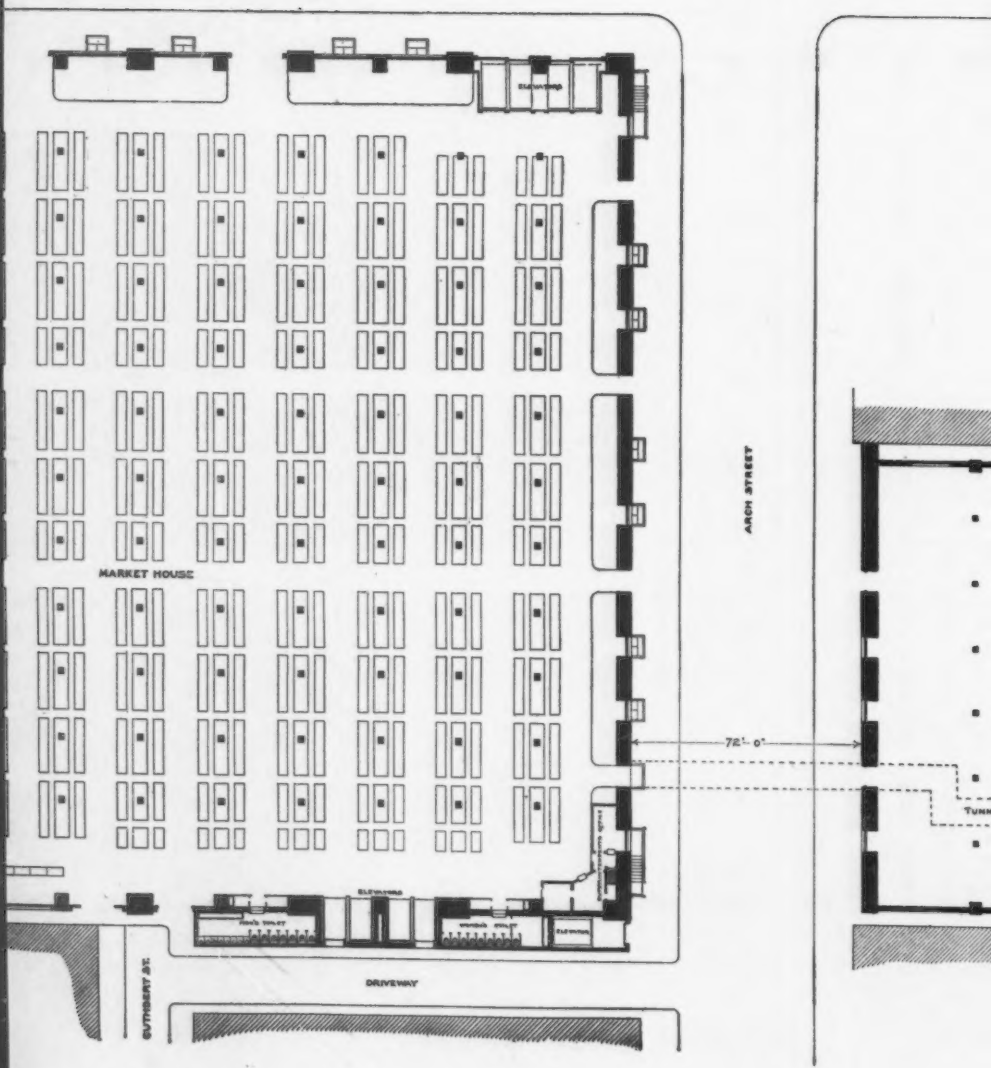
The floor areas of the various rooms in this story are approximately as follows:

	Square feet.
Passenger waiting-room	5 055
Ticket office, exclusive of vaults	1 391
Sub-post office	1 116
Coal and Iron Department, exclusive of vaults	2 830
Ticket storage-room, together with floor in half story above	2 442
Treasury office, exclusive of vaults	4 791
Incoming baggage-room (western room)	7 094
Outgoing baggage-room (eastern room)	6 308


MARKET STREET
DOWN TO BASEMENT STORES
DOWN TO BASEMENT STORES
RAILROAD OFFICES
READING COAL & IRON CO'S OFFICE
LADIES' TOILET
FIREPROOF
TOILET ROOMS
FIREPROOF
TO UPPER WAITING RM.
LOWER WAITING ROOM
TICKET OFFICE
TELEGRAPH OFFICE
TELEPHONE OFFICE
MAIL DEPT.
FIREPROOF
EXIT FROM TRAINS
FIREPROOF
TREASURER'S OFFICE
BURGLAR PROOF
FIREPROOF
ENTRANCE TO OFFICES
DEPARTING BAGGAGE ROOM
OFFICES
OFFICES
ARRIVING BAGGAGE ROOM
HUNTER ST
CAB-STAND


CAB-STAND
DRIVEWAY
PLATFORM
EXPRESS OFFICE
MARKET HOUSE
RESTAURANT
FILBERT STREET
TWELFTH STREET

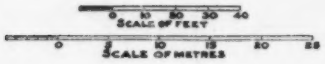
MARKET HOUSE
ARCH STREET
72'-0"
GUTHRIE ST.
DRIVEWAY

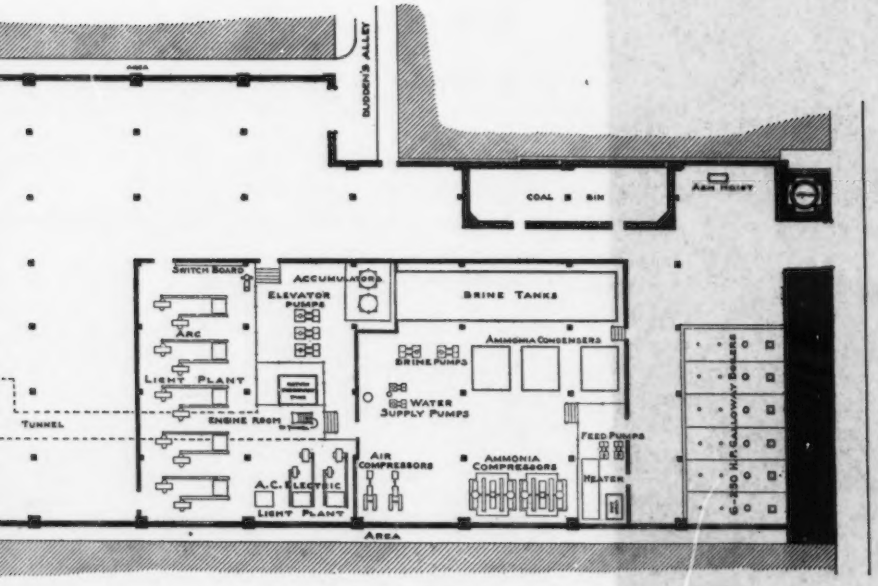

MARKET HOUSE
ARCH STREET
72'-0"
DRIVEWAY
CUTHBERT ST.

PHILADELPHIA AND READING TERMINAL R.R. STATION

TWELFTH AND MARKET STREETS PHILADELPHIA

GROUND FLOOR PLAN





Second Floor.—On the second floor will be found a large general waiting-room occupying the central part of the building with a loggia opening out from it and overlooking Market Street (see Fig. 4). On the east of this room, fronting on Market Street, is the ladies' room with adjuncts, and on the west is a large dining-room, to the rear of which is a restaurant. Back of the ladies' room and accessible from the general waiting-room is the news-room, and still further back are the gentlemen's smoking-room and lavatories opening on to the passenger corridor. Access is gained by a special stairway to a barber shop in a half-story over the lavatories.

The floor areas covered by the several rooms on this floor are :

	Square feet.
General waiting-room	7 857
Ladies' "	2 552
Ladies' toilet-room, etc.	585
News-room	300
Gentlemen's smoking-room	493
Gentlemen's lavatories, etc.	555
Dining-room	3 570
Restaurant	2 676
Serving-room	287

The floors are of marble, except that for the central portion of the ladies' waiting-room a parquet floor is used. Dumb-waiters connect the serving-room with the kitchen department in the top story of the building. The open porch or loggia is a delightful feature of the general waiting-room, extending on the Market Street front for the whole length of the room and affording an opportunity for those necessarily detained at the station waiting for trains to pass the time pleasantly in observing the life and activity in the street.

The Entresol.—East and west of the main waiting-room and between the second and third floor is placed a half-story which is divided into office rooms for the operating department of the terminal, a communication being made between the two portions by means of a gallery in the main waiting-room.

Upper Floors.—The upper floors of the building are used for the general offices of the Philadelphia and Reading Railroad Company, the President's suite being placed on the third floor in the southwestern

part, and having a pleasant feature in a circular oriel window in the recess at the street corner. Contiguous are the rooms for the Board, Secretary, etc. The corridors or hallways on these floors are very spacious, being 16 ft. in width, and the rooms generally have about 20 by 30 ft. floor area, although in some cases a number of rooms are thrown together and in others they are divided up into smaller sizes, depending upon the uses to which they are appropriated. The construction of the building is such that partitions can be placed to suit the wants of the occupants, wherever needed. The upper portions of all partitions on the corridors are formed of glazed sash so as to furnish ample light to the corridors.

The kitchen department for the dining-room and restaurant is placed in the attic and includes a general store-room, pantry, refrigerator, dish-room and serving-room. The tanks for the storage of the water supply for the building are also placed on this floor. Of these there are eight; six of them are each 11 ft. wide, 18 ft. long and 3½ ft. deep, and two, 8 ft. wide, 18 ft. long and 3½ ft. deep, the total capacity at 2½ ft. depth of water being about 27 600 galls. Five of these tanks are for rain water collected from the roof, and three for filtered water. They are connected by a system of main and distributing pipes so that they can be used in unison, separately, or cut off, as may be desired. Photographic rooms are provided in the attic with roof skylight and ample facilities for blue-print copying, with eight printing frames each 48 by 60 ins. Large fire-proof vaults are provided on each floor, built up with brick from the foundations.

Passenger Lobby.—On the second floor between the head-house and the train-shed is the great passenger corridor or lobby, 50 ft. wide and extending in length for the whole width of the station. At the east end of this lobby will be found the office of the station-master and a small room for the postal clerk. Near the west end a wide exit stairway descends to Twelfth Street, and close by is another to Market Street. The floor of the lobby is of cement. Four large floor lights, each of 20 by 32 ft. area, light the baggage-rooms in the story below.

The Train-Shed.—Beyond the passenger lobby is the train-shed, with its great three-centered, pointed arch roof in a single span for the whole width of the tracks, and hinged at the crown and springing line (see Fig. 5). The dimensions of this arch are as follows :

	Feet.	Inches.
Span, center to center of pins at springing	259	8
Height between centers of pins at crown and springing	88	$3\frac{5}{16}$
Total span out to out of building line	266	6
Height from center of pin at springing to starting point of outer curve at eaves	33	$4\frac{1}{2}$
Depth of arch rib at crown	6	0
Pin at crown is placed in center of depth of arch rib	..	..
Depth of arch rib at haunch	12	$4\frac{3}{4}$
Depth of arch rib at springing	4	0
Center of pin at crown to top of ventilator	14	0
Height from pavement to center of pin at springing	20	6
Extreme height from pavement	122	$9\frac{5}{16}$
Length of train-shed, center to center of end trusses	501	8
Width of lobby	50	0
Total length, including head-house measured to building lines	662	$11\frac{5}{8}$
Diameter of pin at crown of arch	..	5
Diameter of pins at base	..	$5\frac{1}{2}$

The exterior curve of each semi-arch has a radius of 120 ft. for an angular distance of $41\frac{1}{2}°$ from the horizontal, and thence a radius of 310 ft. to the crown, while the interior curve has a radius of 50 ft. for an angular distance of $39\frac{1}{2}°$ from the horizontal; thence a radius of 85 ft. for a further angular distance of 22°, and thence a radius of 280 ft. to the crown. The arch is therefore a compound curve, four-centered for the outer flange member and six-centered for the inner flange. Its form and proportions were designed with great care, so as to produce what was judged to give in its outlines the best artistic and architectural effects, and at the same time agree with the requirements of economical construction.

To the architectural engineer the roof is always an interesting study, and when roofs of large span are to be considered, the interest proportionately increases. It is not merely that the space is to be covered with a substantial roof, but the architectural question of an artistic design in harmony with the other parts of the building is of first importance.

A handsome roof is the refinement of engineering construction. The author, some years ago, designed a number of three-hinged arched roofs of the same general type with pointed arch, as in this roof, for the Pennsylvania Railroad Company, one for the Pittsburgh passenger station in 1867 of 158-ft. span, one for Washington in 1872 of 110-ft. span, and one for Jersey City, also in 1872, of 220-ft. span, but they were not adopted and erected on account of the supposed unwarranted expense. Now it has come to be recognized that this is the proper form of roof for a large railway station, reducing to a minimum the destructive action to the iron or steel construction from the sulphurous vapors emitted by the locomotives, and adding essentially to the comfort and satisfaction of travelers by increased ventilation and improved æsthetic effect.

In designing such a roof it is an object to mass the material together as much as possible, avoiding a great number of small pieces and leaving wide open spaces; also to provide ample light and ventilation.

It will be noticed that the arches are arranged in pairs, placed 50 ft. 2 ins. apart, center to center, those of each pair being 5 ft. apart to centers. The spacing brought two pairs of arches over Filbert Street, this street being 51 ft. wide, and the center line of each pair is 5 ins. beyond the house line of the street and the end of the wall. The weights from these arches are carried by wrought-iron girders acting as cantilevers with projecting stone brackets below.

The assumed loading for computations was taken as follows:

	Pounds per square foot.
Weight of trusses, purlins and jack rafters	25
" covering	8
" snow	12
Total	45

Wind pressure was assumed at 35 lbs. per square foot against a vertical surface, the pressure normal to the roof surface being, for the first three panels covering an angle of 41° from the horizontal, 30 lbs. per square foot; for the next six panels comprising an angle of 22°, 20 lbs. per square foot; and for the remaining nine and a half panels of 17°, 15 lbs. per square foot.

The roof was calculated for:

First.—Snow on one side and dead load.

Second.—Snow on both sides and dead load.

Third.—Wind on one side and dead load.

Fourth.—Snow and wind on one side; snow on the other side and dead load.

Calculation was made for the main tie rod with wind alone on the roof, to ascertain if it would always remain in tension.

The roof is constructed of wrought iron, under detailed specifications of the engineers and architects, all that used in the tensile members of open trusses, laterals, pins, bolts, etc., being required to be double rolled after and directly from the muck bar (no scrap allowed), and capable of sustaining an ultimate stress of 52 000 lbs. per square inch on a full section of test piece, with an elastic limit of 26 000 lbs. per square inch and a minimum stretch of 20%, measured after breaking in a length of 8 ins. All other wrought iron was required to be tough, fibrous, uniform in quality throughout, free from flaws, blisters and injurious cracks, and with a workmanlike finish, capable of sustaining an ultimate stress of 48 000 lbs. (excepting for plates over 24 ins. in width, where the requirement was 46 000 lbs.) per square inch on a full section of test piece, with an elastic limit of 26 000 lbs. per square inch and a minimum stretch for that used in tension or transverse stress (except web plates) of 15 per cent. For that used in compression and for web plates not exceeding 24 ins. the minimum stretch was fixed at 10%, and for web plates over 24 ins. at 5 per cent.

The working stresses were taken as follows: Tension, 14 000 lbs. per square inch; compression, 12 000 lbs. per square inch, with a deduction for column length. The calculations were made graphically.

Two intermediate jack rafters of single intersection triangular type are placed between the main arches, and carried by the main purlins, for the purpose of supporting secondary wooden purlins, on which the sheathing is laid. Lateral ties are introduced between the two adjacent arches at each end of the roof, and on each side of the structure throughout its whole length from the eaves up to the first main purlin. The main purlins divide the roof on each side into six panels and are single intersection triangular trusses. The secondary purlins are of yellow pine, 4 by 6 ins., in section, placed about 2 ft. 4 ins. to centers, where the roof is not glazed, and on them is laid $\frac{7}{8}$-in. tongued

and grooved yellow pine sheathing boards, covered with tin. Details of the roof are shown in Figs. 6 and 7.

There is one central ventilator on the ridge of the roof and four side ventilators, all of them glazed, giving a width of glass across the roof of about 126 lin. ft., independent of the glazed gable ends and the windows in the side walls. This large amount of glass, together with the simple design of the roof, the material being massed together in as small a number of pieces as possible, with very few cross-rods breaking up the spaces and disfiguring the main lines of construction, gives an abundance of light and produces a remarkably pleasing effect.

The exterior walls of this part of the building, from the foundations up to the bearing plates of the arches, have concrete foundations, then stone to the ground line, above which they are of brick with pink granite base-course and caps. Above the springing of the roof arch, the side walls are of cast-iron and glass, on wrought-iron framing. The interior finish up to the tops of the windows is of corrugated iron and above that of yellow pine, tongued, grooved and beaded. The wrought-iron framing for the side walls is attached to the arched trusses, and on the side where the rollers of the arches are placed, the wall is cut horizontally just below the track level, the upper portion being suspended from the arches and given ½-in. clearance from the lower part to allow of movement when the arches contract or expand.

Those parts of the gable ends of the roof not glazed are finished in copper, as are also the pinnacles on the pilasters of the side walls. The interior ironwork is painted a shade of Indian red, touched up with black, and the woodwork is finished to show its natural color. The whole effect is extremely pleasing, and much more satisfactory than the usual lead paint finish which so soon discolors from the action of sulphur gases.

There are 13 tracks in the building, arranged in pairs, except for the eastern track, and the passenger footways are 20 ft. wide to curbs, except the eastern one, which is 13 ft. wide.

The floor of the train-shed is constructed of buckled plates carried by plate girders. A layer of concrete is first placed over these plates and on this 1 in. of Neuchatel asphalt, the ties for the tracks being laid in asphalt concrete and the footway pavements formed of Neuchatel asphalt, the top being 8 ins. above the top of rail. Large

frames filled with heavy hammered glass are built in the footways at frequent intervals to provide additional light to the market on the first floor.

The Market.—The whole of the first floor between Filbert and Arch Streets is occupied by the Reading Terminal Market, covering an area of about 78 000 sq. ft., with an average clear height to the underside of main girders of the floor above of 18 ft. The side walls are filled with large windows occupying almost the whole area between the pilasters, and there are also frequent doors opening on to the streets. The floor of the market is formed of brick arches laid in cement and carried on iron beams, the finish on top being of Neuchatel asphalt. In much of this floor, north of the head-house, cement would have been preferred, but it had to be done in the winter season, and in a limited time; hence the necessity of using asphalt. The walls and piers are of brick faced with buff pressed brick.

The market provides for about 1 260 stands (see Plate II), and the stalls are designed on the most approved plan, with iron frames and white oak counter-tops, rails, divisions and lockers, except for a certain number of the stalls and for the fish market, where the counter-tops are of heavy slabs of white marble. Convenient toilet rooms are provided for men and for women. There are eight hydraulic elevators running from the cold storage in the basement to the main-track floor over the market for the transfer of market produce, meats, etc., four of these being located near the corner of Twelfth and Arch Streets and four on the east wall. There is also an elevator on the east wall contiguous to Arch Street, running from the level of the market floor to the cold storage floor.

Market House Restaurant.—The western portion of that part of the first floor between Filbert Street and the cab-stand is occupied by a market house restaurant, with store-rooms, pantry, kitchen and bakery, covering in all an area of 126 by 48 ft., while the eastern part of the same location is arranged as an express office, with a floor area of about 6 250 sq. ft. The whole of the area under the market is excavated and forms a basement which is occupied by cold storage rooms, the clear height of this basement being about 11 ft., and along Twelfth, Arch and Filbert Streets are numerous ventilation areas, 18 in all, extending from the floor up to the pavement level. There are four stairways from the street, two on Arch and two on Filbert Streets; also two

small elevators on Filbert Street in addition to those already mentioned in connection with the market house.

The Power-House.—This building, located under the railway tracks between Arch and Cherry Streets and containing the operating plants for the cold storage and arc electric light system, and also the boilers, covers a space about 285 ft. in depth, 141 ft. in width on Arch Street and 114 ft. on Cherry Street (see Plate II). It is plainly and serviceably constructed of brick and stone, and does not require special description, the tracks overhead being carried by columns and girders. These tracks are laid on stone ballast on a corrugated floor, the corrugated steel pieces forming this floor being of a special section, which, it is believed, has never previously been employed. It was essential to obtain a water-proof floor, and the usual shapes of material would not furnish this on account of the positions of the riveted connections. It was therefore decided to use U-shaped troughs with horizontal outward flanges on the upper edges, and to connect adjacent pieces by a cover plate laid on top and riveted to the contiguous flanges (see detail in Fig. 3). Some of the manufacturers bidding on the work claimed that this shape of piece could not be made, but it was successfully done by stamping cold from ⅜-in. steel plates in 20-ft. lengths, at no greater cost than if the floor had been built with the usual shapes. The steel work was painted with P and B paint, and the hollows or troughs were partially filled and sloped for drainage with a composition consisting of a mixture of coal tar and fine gravel, which became very hard. The drainage is carried from these by a series of galvanized iron corrugated pipes to main drains, hung from the superstructure, and thence to sewers. The work has been a complete success, giving very dry and satisfactory rooms below for the purposes required.

Space is provided at the north end of the house for six boilers, and the stack is at the northwest corner. It is of brick, having a height of 150 ft. above the floor level of the boiler-room and an internal diameter of 7 ft., the base being square, changing to an octagon above, and finishing at the top with a neat cast-iron cap. The core of the stack, which is entirely separated from the external portion, is 13 ins. thick at the lower part for a height of 60 ft., then 9 ins. for a further height of 30 ft., and above that 4½ ins. The exterior is 2 ft. 6 ins. thick at the square base, with 2 ft. 6 ins. additional on the interior

corners, and the octagonal portion is 22 ins. in thickness to a height of 60 ft. above the floor, thence 17 ins. for 30 ft., thence 13 ins. for 30 ft., thence 9 ins. to the top. A large coal bin is provided, which is filled directly from cars on a siding track above, and a hydraulic hoist is arranged so that ashes may be raised and automatically dumped into cars for hauling away. The positions of the cold storage and the arc-lighting plants are shown by the drawings.

The Operating Plant of the Station.—The operating plant comprises the boilers, the heating and ventilation apparatus, the electric plant for the lighting of buildings and roadway, the pneumatic switch apparatus, the elevator machinery, the water supply and the refrigerating apparatus. The entire plant has been so arranged as to allow as much economy in working as possible under existing conditions, and at the same time avoid risk of stopping the operation of the road and station from accident.

The boilers, refrigerating machinery, pumps, and accumulators operating the freight elevators, the air compressors for the switch system, the arc-light dynamo and engines, and the alternating-current incandescent light dynamos and engines are located in the power-house between Arch and Cherry Streets (see Plate II). The direct-current incandescent dynamos and engines, the filters, tanks and pumps for supplying water to the station, the pumps and compression tanks, hydraulic engines, etc., for the passenger elevators, a relay of pumps and an accumulator for the freight elevators, and the pumps, etc., to discharge waste water to the sewer, are located in the basement under the central portion of the head-house on Market Street (see Plate I).

Steam from the boilers is delivered into two 10-in. steam mains, each boiler being connected to each main by 7-in. pipes, and these mains in turn feed the steam supply pipes, of which there are four of 6 ins. diameter, each pipe being connected to each of the two 10-in. mains in the boiler-room. One of these 6-in. pipes supplies the brine pumps of the refrigerating apparatus, the pumps serving the freight elevators, and the engines driving the arc dynamos. Another serves the engines driving the ammonia compressors and the engines of the alternating electric-light dynamos, feed-water and sewage pumps. Supply is also provided from both of these pipes to the air compressors of the switch plant, and the two pipes are so connected that either

one or both can be used for all of the machinery in the power-house. The other two 6-in. steam supply pipes carry steam a distance of 1 200 ft. through the tunnels and cold storage cellar to the head-house engine-room, where they form a loop and supply steam to the engines, pumps, etc., placed there.

The pipes in the power-house are hung from the girders forming the roof covering and carrying the tracks above. In order to avoid danger of accident from vibrations due to movement of locomotives and trains, these pipes are suspended by chains, and the result has been entirely satisfactory, no leaks or trouble of any kind having been experienced in connection with them.

The exhaust steam from the engines and pumps in the Cherry Street power-house is carried by pipes laid in ducts under the floor to a horizontal feed-water heater, with a by-pass so arranged that the tubes of the heater may be removed or repaired without interference with the operation of the plant. The exhaust main from the feed-water heater is 18 ins. in diameter and runs under the boiler-room floor and is carried up outside the stack. The exhaust steam from the engines and pumps in the head-house is also carried by pipes laid in ducts under the floor to the vertical pipe shaft, and up this shaft by a main exhaust pipe 18 ins. in diameter to the attic, and thence by 12-in. pipe to above the roof, where it terminates in an exhaust head. Below this exhaust head a balanced back-pressure valve is placed, so arranged as to open with a pressure of 1 lb. above the atmosphere. Under this valve a 16-in. branch supplies the mains in the attic with the steam required for heating the buildings.

The water of condensation from the heating system is discharged into a tank and pumped back to the feed pumps and thence returned to the boilers. The exhaust steam which passes through the feed-water heater is wasted, and this deficit is made up by the water which runs from the ammonia condenser coils of the refrigerating plant. During the winter the condensation of steam used in heating the head-house is at a maximum and furnishes a large amount of the water returned to the boilers when the refrigerating plant is but lightly taxed. During the summer the increased amount of water from the refrigerating plant makes up the deficiency in the condensation from the head-house, so that the supply to the boilers is constantly kept up and no water is bought for steaming purposes, all heat possible being utilized.

Boiler Plant.—The boiler plant consists of six Galloway boilers, aggregating 1 200 H. P., two feed pumps, four injectors, one horizontal tubular heater, a blow-off tank, a hot well and a hydraulic ash lift. The Galloway boiler was adopted for this location principally on account of the low head-room available, and also because such boilers are readily cleaned, and the character of the water which has to be used is such as to produce large quantities of lime scale.

Each boiler is 7 ft. in diameter and 28 ft. $1\frac{3}{4}$ ins. in length, set as shown on Plate III in an air-tight and well insulated brick chamber, 28 ft. $4\frac{1}{2}$ ins. long by 8 ft. wide by 10 ft. 6 ins. high, inside dimensions, the top of the boiler being placed within 3 ins. of the intrados of the crowning arch. A space of $5\frac{1}{2}$ ins. is left between the shell and the walls of the chamber at the springing line of the arch, and 2 ft. at the back of the boiler. The boiler is supported at its front end in the brick setting and 10 ft. from the rear on a cast-iron expansion rocker. The setting is of hard brick, 18 ins. in thickness, laid in Portland cement, except where it comes close to the hot gases, when lime mortar is used, and a wrought-iron casing of No. 22 B. and S. gauge is built in the wall to prevent air leakage, a brick baffle being constructed to protect the rocker. The spandrels between the arches and the space above them are filled with concrete, the top being finished with a horizontal cement pavement; the exposed walls are faced with white enameled brick, and the front is capped with a course of dressed bluestone. Two cleaning doors, 15 ins. in diameter, are set in the front wall and below the boiler shell. Each boiler has two furnaces, 2 ft. 10 ins. in diameter by 6 ft. 7 ins. long, provided with Tupper grate bars for anthracite pea coal. The boiler shell is made up of seven rings of $\frac{1}{2}$-in. best mild steel, each formed of one plate the full circumference of the boiler, the longitudinal seams being triple riveted and alternate, so as to avoid a continuous line of rivets. The heads are each flanged from one plate $\frac{9}{16}$ in. thick and secured to the shell by the flanges, gusset plates and angle irons. The furnaces are of $\frac{3}{8}$-in. plate, and provision is made for expansion.

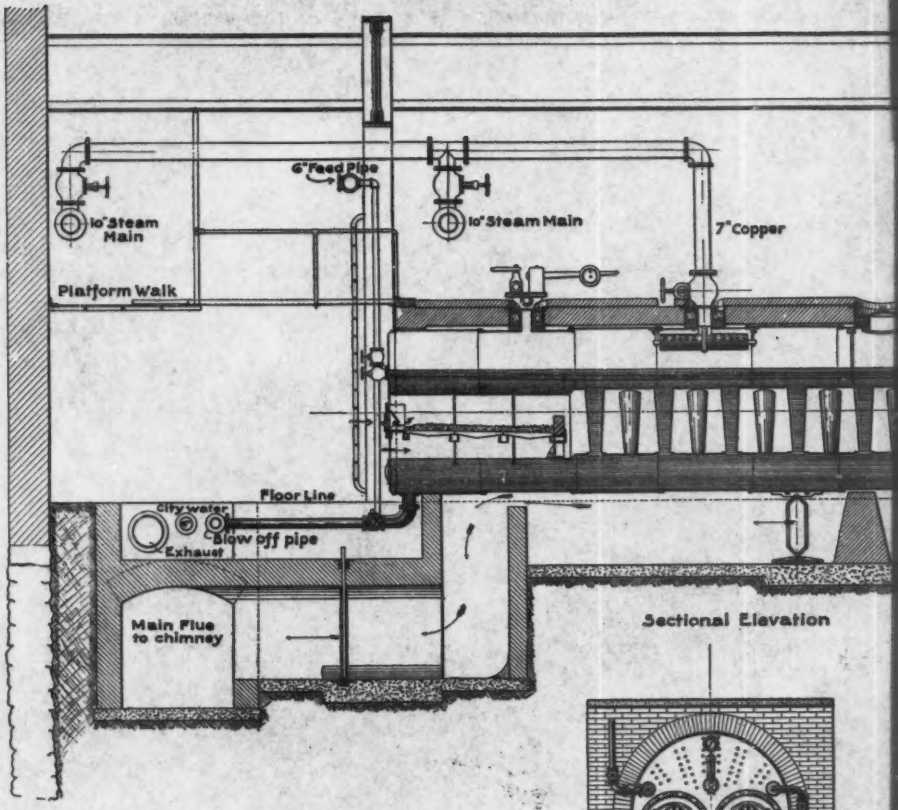
The boiler chambers are lined with fire brick, and each furnace has two suitable fire-clay bridge wall blocks. The furnaces unite behind the fire bridges into one oval flue or combustion chamber, which has large corrugations and contains the cone tubes. The metal in the oval flue is $\frac{1}{2}$ in. thick.

There are in each boiler 33 Galloway cone tubes, which are the essential features of this boiler, each tube being welded and gauged from one plate of $\frac{3}{8}$-in. mild steel and having an internal diameter of $10\frac{1}{2}$ ins. at the upper end and $5\frac{1}{2}$ ins. at the lower end. The tubes are all of the same length and interchangeable. The gases from combustion pass from the furnaces, through the combustion chamber, against the cone tubes and corrugations of the interior shell, and return, enveloping the exterior shell to the damper placed below and under the boiler front, thence to the main flue under the boiler room floor.

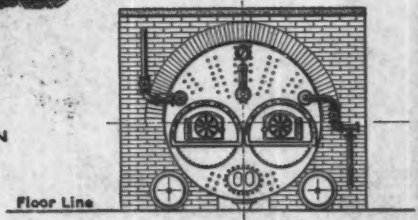
The specification for boilers required the best open-hearth mild steel, free from all cracks and flaws, stamped to show the brand of steel and name of makers, and standing the following physical tests: To have an ultimate strength of not more that 60 000 lbs, nor less than 50 000 lbs. per square inch; an elastic limit of not less than 30 000 lbs. per square inch; a ductility of not less than 25% measured in a length of 8 ins., and a reduction of area at point of fracture of not less than 50 per cent. The test pieces were required to bend cold without crack or flaw 180° to a curve having a radius equal to half their thickness, after having been beaten red hot and quenched in water at 60° Fahr. A variation in cross-section or weight of plates of more than 5% from that specified was cause for rejection.

Each boiler is provided with a manhole 17 ins. in diameter; two nozzles, 7 ins. in diameter; one 2-in. nozzle for surface blow-off; one 4-in. nozzle for blow-off connection; one 2-in. feed nozzle; anti-priming pipe; one 4-in. lever and one 4-in. pop safety valve, and one 7-in. main steam valve; also gauges, valves, dampers, etc. Each boiler has areas, etc., as follows:

Grate surface				36.25	sq. ft.
Water-heating surface in shell		418	sq. ft.		
" "	fire-box	141	"		
" "	oval flue	200	"		
" "	tubes	201	"		
				960	sq. ft.
Steam-heating "	shell			199	"
Total surface				1 159	"
Steam space				211	cu. ft.
Water "				482	"



Sectional Elevation

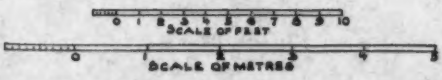


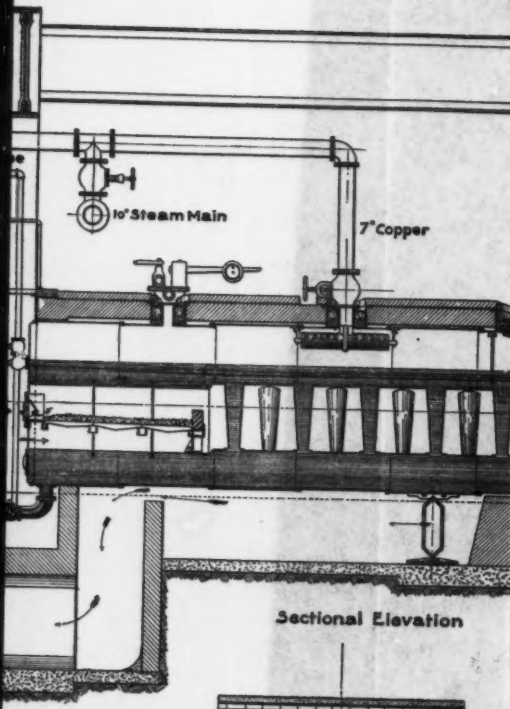
Front Elevation
Single Boiler

PHILADELPHIA AND READING TERMINAL R.R. STATION

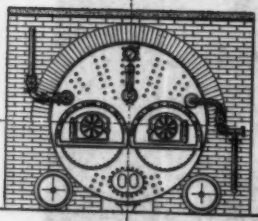
TWELFTH AND MARKET STREETS, PHILADELPHIA

GALLOWAY BOILERS





Sectional Elevation



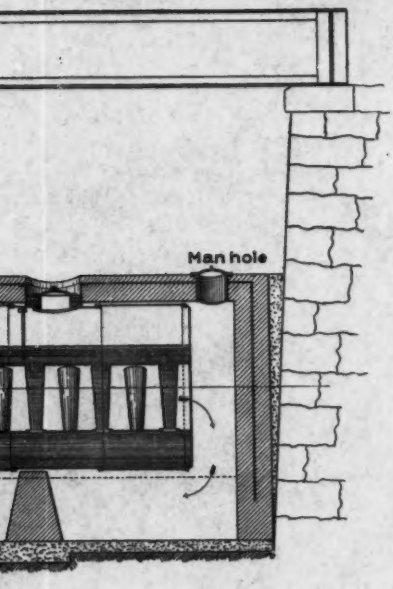
. STATION

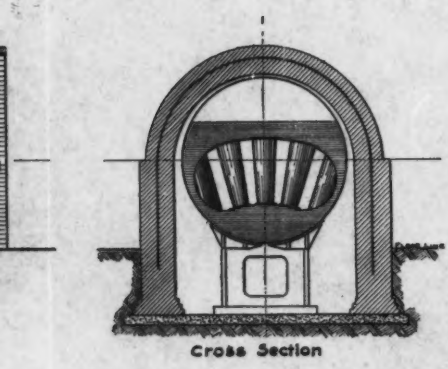
THIA

Floor Line

Front Elevation
Single Boiler

PLATE III.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIV, No. 757.
WILSON ON READING TERMINAL.





Cross Section

The boilers were tested under a hydrostatic pressure of 150 lbs. per square inch for a working steam pressure of 110 lbs. per square inch. The tests for capacity and economy developed the following facts, red ash anthracite pea coal being burned, with a natural draft by the stack, 150 ft. in height.

First Test:

Equivalent evaporation from and at 212° Fahr. per hour	9 485.9	lbs. of water.
Total evaporation (including water in coal) from and at 212° Fahr. per hour	9 563.7	" "
Equivalent evaporation per pound of dry coal from and at 212° Fahr. per hour.	8.13	" "
Equivalent evaporation per pound of combustible from and at 212° Fahr. per hour	9.74	" "
Moisture in steam	0.51	per cent.
Percentage of ash in coal	16.50	"
Dry coal per hour per square foot of grate	32.44	lbs.

Second Test:

Equivalent evaporation from and at 212° Fahr. per hour	8 027.7	lbs. of water.
Total evaporation (including water in coal) from and at 212° Fahr. per hour	8 051.3	" "
Equivalent evaporation per pound of dry coal from and at 212° Fahr. per hour.	8.34	" "
Equivalent evaporation per pound of dry combustible from and at 212° Fahr. per hour	9.90	" "
Moisture in steam	Dry.	
Percentage of ash in coal	15.78	per cent.
Dry coal per hour per square foot of grate	26.63	lbs.
Average steam pressure absolute	106.0	"
Temperature of boiler-room	88°	Fahr.
" back of boiler	680°–810°	Fahr.
" at damper	600°–680°	"

Average test of gases during 10 hours. Parts in 100, by volume:

Carbonic acid	11.58
Oxygen	5.42
Carbonic oxide	0.20
Nitrogen	82.80
	100.00

Approximate weight of air per pound of coal, 16 lbs.

The samples of gas were taken under the various conditions of firing, by which an excess of oxygen might be produced from open furnace doors, or an excess of unconsumed gases from fresh coal being put on the fires, etc.

The feed-water to the boilers can be supplied either from the city water mains, the condensation from the heating systems of the buildings, or the overflow from the ammonia condenser of the refrigerating apparatus. It is delivered into an iron tank, from which it is taken by two Blake duplex feed pumps, having 10-in. steam cylinders, 6-in. water plungers and 12-in. stroke, each pump being capable of supplying all of the six boilers. From the pumps the water passes through a horizontal tubular feed-water heater of the reservoir type, 19 ft. 6 ins. long and 54 ins. in diameter, containing 49 lin. ft. of 2-in. seamless drawn brass tubes, measuring 650 sq. ft. of heating surface, and is carried by a 6-in. main to the boilers, with a temperature, after leaving the heater, of 212° Fahr. The capacity of the heater is 1,890 galls. A further auxiliary supply is obtained from four No. 8 Sellers fixed nozzle automatic injectors, each having a capacity of 13 500 lbs. of water per hour. Each boiler is supplied from the 6-in. feed main by a 2-in. feed pipe, this pipe being carried through the front head and discharging under the surface of the water near the rear of the boiler. The blow-off pipes are 3 ins. in diameter, and discharge through a 4-in. main blow-off pipe, laid in a duct under the floor and above the main flue, to a muffler in a blow-off tank. This tank is 23 ft. 10 ins. long and 5 ft. 2 ins. in diameter, made of ½-in. wrought iron and provided with an 18-in. manhole, a 6-in. vapor pipe and a 6-in. outlet to a sewer. It is located under the roadway to the boiler-room, near the stack.

The main flue is 133 ft. long to center of stack, and has an area at its smaller end of 19 sq. ft., and at the larger end, at the stack, of

40.4 sq. ft. The inlets for each boiler have an area of 14.6 sq. ft. This flue is built of hard brick and Portland cement mortar, is under the boiler-room floor, and above it is the duct, previously mentioned, for the blow-off pipe and for the exhaust main from the feed-water heater.

Each boiler is provided with an individual damper, and a main damper, operated by an automatic regulator, is placed in the flue at the stack. The boilers are controlled entirely from the front, the rear of the boiler-setting abutting against the Cherry Street Bridge abutment. A light iron gallery at the level of the top of the boilers extends the entire length of the 10-in. steam mains, and is connected to the top of the boiler setting, three iron ladders giving access to this gallery for the ready manipulation of valves, etc.

The coal bins, previously mentioned, are of brick, and extend from the boiler-room floor to the track level. They have a siding directly over them, from which coal is dropped into them. They are capable of holding 450 tons. An ash-lift is provided, operated by hydraulic power from the accumulators, and automatically dumps the ashes into cars at the track level. It has a capacity of 51 cu. ft., and the bucket drops into a pocket level with the floor of the boiler-room, allowing easy deposit of ashes.

Heating.—The head-house is heated by direct radiation throughout. The exhaust steam from the machinery in the basement is carried by an 18-in. main up the pipe shaft to the attic, where it is connected to a system of horizontal pipes running around the exterior walls in a loop. Supply pipes controlled by valves are carried from these horizontal pipes by a bottom connection to the various radiators on all the floors of the building above the second. The basement, first and second floors are served from a system of pipes in the basement, connected with the exhaust main, these supply pipes also serving as bleeders for the supply from the attic. All of these pipes are drained to traps discharging into the main drip from the heating system. The condensation from the radiators flows into vertical risers, thence to the main drip in the basement and cellars, which discharges into traps from which it is taken to a 300-gall. drip tank, constructed of $\frac{3}{16}$-in. iron and provided with manhole, water-gauge, vapor pipe, and necessary outlets.

A duplex pump with a capacity of 40 galls. per minute delivers the

water from the drip tank through a 2½-in. pipe to the hot-well in the Cherry Street power-house. This pump is operated automatically by the height of water in the drip tank, and a relay pump is also provided in case of accident. Air outlets controlled by stop and check valves are provided on the drip pipes and discharge into the vapor pipe. The individual parts of the heating system are controlled by gate valves on the steam and drip pipes. The rooms of the building with north and west exposure have 2 sq. ft. of radiator surface, and those with south and east exposure 1 sq. ft. to each 100 cu. ft. of content.

The main supply riser is proportioned to give a sectional area of 0.007 sq. in., and other steam supply pipes 0.012 sq. in. to each square foot of radiating surface, no pipes being allowed of less than ¾-in. diameter.

The drip pipes are proportioned as follows:

1-in.	pipe for	150 to	300	sq. ft.	radiating surface.
2-in.	"	600 to 1 600	"	"	"
3-in.	"	3 200 to 7 000	"	"	"

The intermediate sizes are proportioned accordingly.

Provision is made for a supply of live steam controlled by a pressure regulator, should the exhaust from the machinery in operation be insufficient. In practice this is only occasionally necessary in the early morning. The steam pressure required in the heating system varies from 1 lb. above the atmosphere to 5 ins. of vacuum.

The baggage-rooms, restaurant and toilet-rooms in the market house, the pipes serving nozzles for warming cars in the train-shed, and pipes for clearing rain conductors of ice or snow, are supplied from the live steam mains and controlled by pressure regulators, the drips from these heating surfaces and from the traps draining steam mains, etc., being discharged by a pipe into a drip tank at the end of the tunnel at Arch Street, from which it is pumped into the hot-well.

Ventilation.—The rooms and offices above the second floor are ventilated by exhaust fans located on the roof, and the various air conductors are of galvanized iron, being proportioned to convey the air at a velocity of 600 ft. per minute. Two 60-in. Blackman fans are provided for this purpose, each rated at 12 000 cu. ft. per minute. There is also one 42-in. Blackman fan of 9 000 cu. ft. per minute, specially provided for exhausting the air from the large toilet-rooms in the

eastern end of the building. Each fan discharges its air above the roof by a galvanized iron tower, designed to prevent adverse air currents.

Individual toilet-rooms are ventilated by aspirating coils in flues, these coils being supplied with steam from the high-pressure pipe serving the kitchen department and controlled by pressure regulators. The vent flue registers are located in the side walls of the various rooms above the baseboard, and those from the toilet-rooms are connected to the seat vents of the Sypho water-closet hoppers, each hopper having an air vent of 12 sq. ins.

The 60-in. fans are driven by 5 H.-P. electric motors, and the 42-in. fan by a 2½ H.-P. motor.

The basement stores are ventilated from the floor by galvanized iron ducts and a 30-in. Huyett & Smith disk fan, driven by a 1 H.-P. electric motor, the air being delivered at a rate of 6 000 ft. per minute at the base of the pipe shaft, which has on top a 30-in. Star ventilator.

Arc-Lighting Plant.—The arc-light plant has a total capacity for operating three hundred 2 000 nominal candle-power arc lamps in 10 circuits, with a maximum of 30 lamps on each circuit. Two hundred and forty lamps were installed under the contract, distributed as follows:

66 lamps in the train-shed on two circuits, and from the circuit lighting the streets and cab lobby.
44 lamps in the market house, on two circuits.
12 lamps in streets and driveways around buildings.
28 lamps on line of road between Arch and Callowhill Streets, on five circuits.
48 lamps on branch line to Broad and Noble Streets and beyond Broad Street, on two circuits.
12 lamps on branch line to Ninth and Green Streets, on three circuits.
38 lamps in station at Spring Garden Street, Ninth Street yard and engine houses, etc., on three circuits.

The lamps in the train-shed are suspended over each platform, at distances apart of 50 ft., with the arc 16 ft. above the floor. The conductors run across the shed, 28 ft. above the floor, and are stayed over the center of each platform from the front to the rear of the shed with phosphor-bronze wires of No. 12 B. and S. gauge. These lamps in the

train-shed have full opal glass globes, thus giving perfect illumination without shadows. The lamps on the line of the road are erected on poles, with the arc placed 30 ft. above the track level, and between Arch and Callowhill Streets are spaced generally 100 ft. apart on each side of the road. The lamps are located so as to also illuminate the streets passing under the road. On the branch lines, the lamps are located on the right of the outbound track, at distances apart of about 125 ft.

The tracks are served by five circuits, as already stated, but the lamps are so connected that two of the circuits may be cut out and yet leave a sufficient number of lamps in service to operate the road.

The poles for the road lines are of Michigan pine, 5 ins. square at the top and 10 ins. square at the level of roadway, those between Arch and Callowhill Streets being set either in wrought-iron pedestals or secured by iron clamps to the masonry, and those on the branch lines set 7 ft. in the ground, on large flat stones and well tamped. The poles are dressed and painted in three coats of white lead and oil, and are provided with iron ladders. The conductors are carried up the poles in moldings, and each lamp is provided with a cut-out switch in a cast-iron box with Yale lock, set 4 ft. above the track, and so arranged as to cut out the lamp without breaking the circuit of the other lamps. All of these lamps on the roadway have clear glass globes.

The electrical conductors go out on the right and return on the left side of the roadway, those between Arch and Callowhill Streets being laid in 1¼-in. wrought-iron pipes, either on the coping or under the surfaces of the ground. Brass slip joints are provided for expansion and contraction, and cast-iron junction boxes at each lamp. On the iron elevated construction the conductors are carried under the footways, on glass insulators. All lamps are suspended independently from the conductors.

There are 10 direct current automatic Western Electric arc dynamos, each having a capacity of 30 10-ampere 50-volt lamps, at a speed of 1 400 revolutions per minute, and guaranteed to operate with a power not exceeding ¾ H. P., delivered at the dynamo pulley for each lamp burning. The dynamos are operated by five Westinghouse compound engines (one engine driving two dynamos), connected up with Schultz endless leather-link belts. This type of belt is used throughout the

plant. Each engine has a 10-in. high-pressure cylinder, an 18-in. low-pressure cylinder and a 10-in. stroke, and at 320 revolutions per minute, with 100 lbs. steam pressure, and one-fourth cut-off, it is guaranteed to deliver 65 H. P.

The switchboard is of Tennessee marble and is fully equipped with spring jacks, plugs, ampere meters, lightning arresters, magneto bell, volt meter, etc.

The lamps are 2 000 candle-power of two carbon, Western Electric manufacture. All conductors are of No. 4 B. and S. gauge; those in the underground conduits have simplex triple-braided double extra mining insulation, and those for all other work, triple braided weather-proof insulation.

Incandescent Electric Light Plant.—The incandescent electric light plant is served by both alternating and direct current dynamos. The alternating current apparatus is located in the Cherry Street power-house and serves the lights in the power-house, the market offices and toilet-rooms, the cold storage rooms, the tunnels and basements, the kitchen, restaurant, express rooms, station-master's office and relay lamps in the passenger corridor; also two 500-light (equivalent to 1 000 16 candle-power lamps) converters in the head-house engine-room.

There are two 45-kilowatt Westinghouse alternating current incandescent dynamos with separate exciters driven from the engines, each exciter having a capacity of 30 amperes at 125 volts, the primary current being 1 000 volts and the secondary 100 volts. Each dynamo is driven by a compound Westinghouse engine with a 12-in. high-pressure cylinder, a 20-in. low-pressure cylinder and 12-in. stroke, rated at 100 H. P., with 100 lbs. steam.

In addition to the various circuits serving the lamps as indicated, a pair of No. 4 B. and S. mains is run to the 1 000-light converters which are connected with the head-house distribution switchboard and act as a relay to the direct current incandescent dynamos, as will be hereinafter described.

The direct current incandescent lighting apparatus serves all lamps in the head-house, the motors driving the ventilating fans and the transformers serving current for all the telegraph lines centering in the building. There are three Westinghouse 75-kilowatt, multiple, direct current incandescent light dynamos, each of 600 amperes, at

125 volts. Each of these dynamos is driven by a Westinghouse compound engine, having a 13-in. high-pressure cylinder, a 22-in. low-pressure cylinder and a 13-in stroke, and of 125 nominal horse-power, with 100 lbs. of steam (see Plate I).

The switchboard is of white marble, 18 by 9 ft., supported by brass pedestals. It has two pairs of bus-bars, one pair for alternating current and the other for direct current. The 36 circuits serving the building are each provided with a double pole, double throw, jaw switch, and four spare switches are supplied for additional circuits that may be needed. Each circuit is furnished with two cut-out switches on each pole, so that in the event of the failure of a fuse a second fuse can be thrown into circuit by the closing of the auxiliary switch. Each of the circuit switches is connected to both sets of bus-bars, so that when thrown up they feed the circuits from the direct current bus-bars, and when thrown down from the alternating current bus-bars.

There are provided upon the switchboard for each dynamo its appropriate switches, rheostat, ammeter, volt meter, and upon the top of the board an ammeter indicating the load on the alternating current dynamos in the power-house. This arrangement of the switchboard is somewhat novel, and was so designed as to utilize the spare power of the alternating current machines and avoid the necessity of a spare direct current dynamo.

There are also provided four revolving transformers of different sizes, taking the current at 100 volts from the switchboard and transforming it to 6 volts, 20 volts and 70 volts respectively, for the operation of all the telegraph lines in this building belonging to the road and its connections.

From the fact that the station was put into service before the work was completed, it was impossible to make a test of the engines of the electrical plant, but a test made at the Drexel Institute of similar engines, with 10-in. and 18-in. cylinders and 10-in. stroke, gave the following results. The test was made during a run of five hours after the engines had been in commission for several months. The conditions for the tests were not as favorable as they might have been, as all of the water supplied to the boiler (of 200 H. P. capacity) during the test was weighed and charged against the engine, the steam having been delivered through long lines of large mains.

Test No. 1, *Full Load.*

Engine rating	65 H. P.
Steam	98.1 lbs.
Atmosphere	14.72 "
Horse-power, mean, high-pressure cylinder	33.47
" " low-pressure cylinder	30.19
Total	63.66 H. P.
Water per horse-power per hour	26.08 lbs.
Revolutions per minute	320
Variation	314 to 329

Test No. 2, *Partial Load.*

Engine rating	65 H. P.
Steam	96.2 lbs.
Atmosphere	14.72 "
Horse-power, mean, high-pressure cylinder	24.49
" " low-pressure cylinder	16.75
Total	41.24 H. P.
Water per horse-power per hour	28.79 lbs.
Revolutions per minute	320.5
Variation	320 to 322

There are installed in all, including current for motors, an equivalent of 4 200 16 candle-power lamps. For general illumination one 16 candle-power lamp is allowed for 1 000 cu. ft. of content, which of course does not include special desk lighting. The entire wiring is run on the two-wire system. No wires less than No. 14 B. and S. gauge are used, and wires of No. 8 and larger sizes are stranded. The insulation is as follows: Simplex double extra mining for high tension alternating currents, primary circuits. For the secondary circuits, Bishop double coat. For the direct current incandescent wiring fire and and weather-proof insulation is used.

The general layout is figured for 16 candle-power 100-volt lamps, on a basis of 1.2 amperes per lamp, with a loss not exceeding 5 volts, and a difference of 1% between any two lamps on the same circuit, with all lamps burning.

The conductors are run in brass armored conduits for all rooms below the third floor, but above that they are run in molding, this method having been adopted to enable the ready change in position of lamps, as might be required to suit the various office requirements.

The attic is served with one circuit, and the third to seventh stories inclusive are each served with two main circuits, the feed wires being carried in vertical cabinets, one in the center of the eastern half of the building and the other in the western half. Each main feed wire serves a "crib," run on the ceiling of the central corridor, from which taps are made with link-fuse cut-outs. Each stairway has its own circuit, which also carries lamps for the ends of the corridors. Circuits for the remaining lamps are arranged so as to admit of easy control by the engineer, and the switches and cut-outs in those portions of the building open to the public are set in metallic boxes, flush with the walls, and provided with Yale locks.

Pneumatic Switch and Signal Apparatus.—The pneumatic switch and signal apparatus was installed by the railroad company and is operated by two No. 7 Ingersoll-Sergeant Drill Company's straight-line compressors, each having a 14-in. steam cylinder, a 14½-in. air cylinder, and an 18-in. stroke, the fly-wheel being 5 ft. in diameter. One compressor, with 100 lbs. of steam and working at 36 revolutions per minute, is sufficient to run the apparatus. Connections are made with two steam mains to each compressor, and the electrical storage batteries are charged by an 80-ampere dynamo at 50 volts, connected directly to and driven by a standard 10 H.-P. Westinghouse engine, having 5½-in. steam cylinders and a 5-in. stroke.

Elevator Plant.—There are 15 freight and baggage elevators and six passenger elevators, all operated by hydraulic power and of the Stokes & Parrish type. The freight and baggage elevators are worked by rams under a pressure of 250 lbs. per square inch at a speed of 80 ft. per minute at half load. Three pumps, two accumulators and a return tank are located in the Cherry Street power-house of sufficient capacity to operate the entire plant, and two pumps, one accumulator and a return tank are placed in the engine-room of the head-house. These separate installations are arranged to operate either together or separately, one being the relay of the other. During the winter months the head-house pumps may be run in order to allow the exhaust steam to be used for heating purposes. The pressure and return mains serv-

ing the various elevators are placed in the tunnels and ducts under the exterior corridors of the cold storage cellar, and are controlled by valves, so that either or both of the operating plants may be used. In case of an accident to the main pipes the damaged portion may be cut out without impairing the efficiency of the service.

Each accumulator has a piston of 17 ins. diameter, with a stroke of 6 ft., and is loaded with 32 tons. The pumps are of the Worthington compound duplex pattern with outside-packed pistons, having 14-in. high-pressure and 20-in. low-pressure cylinders, 7¾-in. water plungers and a 15-in. stroke.

The return tank in the Cherry Street power-house has a capacity of 650 cu. ft., that in the head-house 340 cu. ft., and the force and return mains are 7 ins. in diameter.

The table on page 156 gives the general data in reference to the various freight and baggage lifts.

Of the six passenger elevators, four of them are rope hoist and two of them operated by rams, working under a pressure of 110 lbs. per square inch. The apparatus, which is hydraulic and pneumatic, its location being shown on Plate I, is as follows: Two Worthington duplex compound pumps with 14-in. high-pressure and 20-in. low-pressure cylinders, 12-in. water plungers and 10-in. stroke. Two horizontal wrought-iron pressure tanks each 22 ft. long and 5 ft. in diameter. One auxiliary vertical pressure tank 4 ft. in diameter and 6 ft. long. One return water tank having a capacity of 660 cu. ft., and one auxiliary tank of 66 cu. ft. One hydraulic engine with 18-ft. 1-in. stroke, 22½-in. cylinder, geared 8 to 1, two steel 1$\frac{15}{16}$-in. piston rods. One hydraulic engine with 17-ft. stroke, 22½-in. cylinder, geared 8 to 1, two 1$\frac{15}{16}$-in. piston rods. One hydraulic engine with 20-ft. 5-in. stroke, 18-in. cylinder, geared 6 to 1, two 1$\frac{15}{16}$-in. piston rods. One hydraulic engine with 20-ft. 5-in. stroke, 18-in. cylinder, geared 6 to 1, two 2$\frac{3}{16}$-in. piston rods.

The auxiliary pressure and return tanks are used to equalize the flow of water to the pumps from the elevators in the west end of the building. The water is pumped from the return tank to the pressure tanks (which are kept half full of air by means of snifting valves) and is delivered from them to the cylinders of the hydraulic engines. One duplex pump and pressure tank is sufficient to operate the elevators, and the duplicates are held in reserve.

TABLE GIVING GENERAL DIMENSIONS AND DATA OF BAGGAGE AND FREIGHT ELEVATORS FOR THE PHILADELPHIA AND READING TERMINAL RAILROAD STATION, PHILADELPHIA, PA.

LOCATION.	Style.	Lift.	Size of car.	Net capacity in pounds.	Speed with one-half load per minute.	Working pressure on piston not to exceed	Diameter of ram or piston.	REMARKS.
South end of train-shed { Outgoing baggage	Direct ram	23′ 3″	8′ 0″ x 13′ 6″	6 000	80′	300 lbs. per square inch.	8½″	Lift from street to track level.
South end of train-shed { " "	"	23′ 3″	8′ 0″ x 13′ 6″	6 000	80′	300 " "	8½″	" " "
South end of train-shed { Incoming baggage	"	23′ 3″	8′ 0″ x 13′ 6″	6 000	80′	300 " "	8½″	" " "
South end of train-shed { " "	"	23′ 3″	8′ 0″ x 13′ 6″	6 000	80′	300 " "	8½″	" " "
Filbert Street	"	11′ 9″	7′ 0″ x 3′ 6″	2 240	80′	300 " "	5½″	" basement to street.
" "	"	12′ 0″	7′ 0″ x 3′ 6″	2 240	80′	300 " "	5½″	" " "
Twelfth Street	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " track level.
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "
Arch Street	"	12′ 6″	8′ 6″ x 12′ 2″	6 000	80′	300 " "	8½″	" " street level.
East of shed, etc.	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " track level.
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "
" "	"	35′ 8″	7′ 6″ x 13′ 3″	6 000	80′	300 " "	8½″	" " "

One of the elevators is arranged to lift 6 000 lbs., so that safes and other heavy articles may be conveyed by it. The ram elevators are served from the pressure tanks. The elevators are provided with safety apparatus and speed governors which arrest the descent of the car if it exceed a safe speed from any cause. Should this apparatus fail, the car drops into an air cushion 17½ ft. in depth, which is ample to prevent breakage of the car or loss of life.

The table on page 158 gives the general dimensions of the passenger elevators.

Water Supply.—The water supply is from the city mains and from the rainfall on the roof of the head-house. In the basement of the head-house there are two Jewell pressure filters, one filtered water tank and three Worthington pumps; in the attic there are eight storage tanks, which have been previously mentioned in the general description of the building, and in the Cherry Street power-house there are two Worthington pumps, a brick cistern and a pressure tank (see Plates I and II).

Water from the city mains on Market Street is supplied to the filters through a meter, and a direct supply, without a meter, with sealed valve, is also furnished for fire service. The water through the filters serves the head-house and the pipes delivering at the end of each track in the train-shed for a supply to passenger cars; the rainwater collected from the roof, supplemented from the pumps when necessary, is used to flush the water-closets; and the market, restaurant, etc., under the train-shed, are furnished directly from the water mains on Twelfth Street. The power-house is served by a 6-in. main connected with the city mains on Arch and Cherry Streets, and fire hydrants in the cold storage cellar and in the train-shed are furnished from the Arch Street main as well as from the pumps serving the ram elevator system, check valves being introduced so that a pressure of 250 lbs. per square inch can be brought into service if required. The cistern and pump in the power-house are held in reserve in case of accident to the city mains or in the event of the city pressure falling below the pressure that is required to serve the cold storage machinery.

The two filters in the head-house have a total capacity of 20 000 galls. per hour, each consisting of a wrought-iron shell 8 ft. in diameter, containing 200 discharge nozzles ⅜ in. in diameter fitted with finely perforated rose screens of aluminum bronze 1¾ ins. in diameter.

TABLE GIVING GENERAL DIMENSIONS AND DATA OF PASSENGER ELEVATORS FOR THE PHILADELPHIA AND READING TERMINAL RAILROAD STATION, PHILADELPHIA, PA.

LOCATION.	Style.	Lift.	Size of car.	Net capacity in pounds.	Speed with one-half load per minute.	Working pressure on piston not to exceed	Diameter of ram or piston.	REMARKS.
Head-house, west...	Rope hoist.	133'	6' 0" x 5' 6"	2 240	500'	110 lbs. per square inch.	18"	Lift from cellar to sixth story.
" " ..	"	123'	6' 0" x 5' 6"	2 240	500'	110 " " "	18"	" basement to sixth story.
" east....	"	123'	6' 9" x 4' 9"	2 240	500'	110 " " "	18"	" " " "
" "	"	123'	6' 9" x 4' 9"	*6 000	500'	110 " " "	18"	" " " "
Waiting-room	Direct ram.	23' 3"	6' 0" x 8"	3 000	200'	110 " " "	9"	" street to track level.
"	"	23' 3"	6' 0" x 8"	3 000	200'	110 " " "	9"	" " " "

* 6 000-lb. load is for lifting safes at slow speed. Passenger load to be 2 240 lbs.

The water from these nozzles passes through a bed of crushed quartz 2½ ft. in depth. In cleaning the filters the direction of the water is reversed and is admitted to the underside of the quartz bed, which is agitated at the same time by a revolving comb operated by an electric motor. For the purpose of sterilizing the filters, high-pressure steam can be admitted to the discharge chamber and forced back through the nozzles. The tank for filtered water, also in the basement of the head-house, is built of wrought iron in two compartments and is of 10 000 galls. capacity.

The three pumps in the same location have the following dimensions : Two Worthington compound duplex pumps, 10-in. high-pressure and 16-inch low-pressure cylinders, 8-in. water plunger and 10-in. stroke ; and one Worthington fire pump, 17-in. steam cylinder, 10-in. water plunger and 15-in. stroke, the pumps being connected so that they can be operated either separately or together.

The tanks in the attic are of wrought iron and have a capacity of 27 600 galls. Fire nozzles are provided in the various stories of the building at convenient points and are supplied directly from the tanks, as well as from the fire main, being so controlled by check valves that when the fire main is in service the high pressure from the pumps can be utilized automatically. The cistern in the power-house is of brick, laid in cement, and is 9 ft. in diameter and 13 ft. deep. It is fed by a supply from the city mains. Connected with this cistern are two Worthington duplex pumps, having 7½-in. steam cylinders, 7-in. water plungers and a 10-in. stroke, and a pressure tank 3 ft. in diameter and 12 ft. long.

Drainage.—Drainage wells are provided for all wastes draining below the levels of the city sewers, and steam pumps to discharge their contents into the sewers.

Cold Storage.—It has already been stated that the basement or cellar under the market-house is occupied by cold storage rooms. The space between the exterior walls and the first row of pier columns, all around the basement, is reserved as a wide passageway, and under its floor is a duct to carry service pipes from the tunnel to elevators, etc., as previously described. The whole of the area inside of the outer rows of pier columns is intended to be ultimately filled with cold storage rooms and corridors, and the air-locks in connection with them. At present about two-thirds of the space is so occupied. The

total capacity of the various rooms, when complete, will be 377 940 cu. ft., and of the corridors 63 450 cu. ft. There are already constructed 236 460 cu. ft. of rooms and 43 740 cu. ft. of corridors. The rooms are of different sizes, varying from about 5 000 to 17 000 cu. ft. each, and have a clear height under the drip-boards, near the ceiling, of 6 ft. 9 ins. They are arranged to be used at different temperatures varying from 3° to 44° Fahr., and were constructed for a test temperature of 5° above zero as a maximum which had to be maintained throughout the entire system of empty rooms for at least 36 continuous hours in the months of June, July or August. Particular care must be taken in the construction of such rooms, to arrange that, when in use, the air in them shall be kept very dry. This is satisfactorily accomplished by means of air-locks having doors closing automatically. The freezing-rooms are each provided with five such air-locks and the other rooms with three or four, as may be necessary (see Plate I).

The lumber used in the construction of these rooms is dressed spruce, a material that does not communicate any taste to articles placed in storage. The outside partitions and ceilings have six thicknesses of boards with two air spaces of 1 in. each, and the inside and cross-partitions have generally four thicknesses of boards, with one air space of 4 ins., except for freezing rooms, where they are like the exterior walls. Partitions for swinging doors in corridors and vestibules have two thicknesses of boards, one vertical and one horizontal, without any air space, nailed to 2 x 4 in. studs and inter-ties. The boards in all cases are thus arranged in pairs, and between the boards of each pair there are three layers of red Neponset paper, 1 oz. per square foot, with 3-in. lapped joints. All air spaces are divided by strips forming cells to prevent circulation of air, and in the ceiling to form nailing pieces for boarding.

The floor is of asphalt, ½ in. thick, laid on a concrete base. Cement curbs are formed for the partitions and doorways, overlaid with asphalt, made airtight and protected at the doorways by wrought iron plate coverings set in the asphalt. All sills for partitions are bedded in asphalt. Secondary floors of spruce are laid in the freezing-rooms over the asphalt with an air space between.

The doors to cold storage rooms are built over an inside frame of stiles and rails 1¼ ins. thick, paneled flush with narrow matched ⅜-in. boards rabbeted in and having three layers of red Neponset

paper underneath, the joint between boards and frame being calked tight. Three layers of the same paper are placed on both sides of the doors, and secured by canvas covering over felt edging; outside stiles and rails are then put on and diagonal boarding cut in between.

The corridor doors are made of 1⅜-in. matched boards, planed and beaded, with all outside edges rounded, secured together by ⅞-in. ash battens, placed on both sides and having galvanized iron clinch nails passing through both battens. Particular care has been taken in the construction of the frames for the doors and in hanging them to prevent the admission of air around them. The edges of the doors are beveled and the felt on them secures tight, close fitting when the doors are shut. All doors are double, and air-lock doors are double swing.

Overhead wrought-iron tracks for handling and transporting material for storage are provided throughout certain of the rooms and corridors. They are carried by hangers, made perfectly level and furnished with swinging bars, hinged at one end, as switches, so that change may be made to any track desired. No curve is used of less radius than 7 ins., and the rollers for the tracks are made as large as practicable, the wheels being of cast-iron and the frames and hooks of wrought iron.

Drip-boards are formed of two ⅜-in. thicknesses of spruce, each planed and matched, laid in opposite directions and having three sheets of Neponset paper between them. On these are ⅜-in. battens, both crosswise and lengthwise, with three additional layers of Neponset paper on top. A second set of crosswise battens is then placed over the first, with corrugations cut in them; and on these galvanized corrugated iron is laid, another batten being placed at the upper end, also cut to suit the corrugations, to keep the iron in place. Angle irons are used underneath for additional stiffening. The boards are fastened together with galvanized iron clinch nails, and the corrugated iron is secured by rivets. The drip-boards are hinged at the lower end and secured by hooks at the upper end. They have a fall of about 1 in 60. Gutters are placed at the lower ends of the drip-boards, formed of spruce with white lead joints. They connect with gutters at the ends of the rooms, and from these 2-in. wrought-iron water pipes pass through the partitions to the corridors or vestibules, provided with bends and check valves on the outside where the drip can be collected in buckets. Every care is taken to calk all openings and make them thoroughly air-

tight; all those for track hangers are protected from leakage; all drip-boards abutting against columns have curbs to prevent water from running down the column, and there are innumerable details that cannot be stated in this paper.

The temperatures in the various rooms are maintained within 2° of that required for the various conditions, which, as already stated, vary from 3 to 44°. Brine is used for cooling the rooms and is circulated in coils of 1½ ins. diameter through wrought-iron pipes, there being at least four independent coils in each room; they are usually placed overhead above the drip-boards, the latter aiding to induce a circulation of the air. The coils are so arranged that the entire content of the room is equally cooled with one or more coils in service, and generally there is an area of cooling surface equal to the square feet of ceiling in the room, an increase beyond this being made in the freezing-rooms to meet requirements. The refrigerating apparatus consists of ammonia compressors, ammonia condensers, brine tanks, brine pumps and mains. The apparatus, except the mains, is in duplicate.

The condensing pressure for the ammonia is 145 lbs. per square inch and the evaporating pressure for the ammonia is 5 lbs. per square inch. The difference of temperature between initial and waste water in the condensers is 10° Fahr., and the difference of temperature between the initial and return brine is 3°.

There are two vertical Boyle ammonia compressors specially designed for this plant, each having a capacity for refrigeration equal to 75 tons of melting ice in 24 hours. Each compressor has two single-acting ammonia cylinders of 15 in. diameter and 30-in. stroke, driven by a Corliss engine, with 20-in. cylinders, 36-in. stroke, and two fly-wheels of 8 ft. diameter. The shaft of the engine is 10 ins. in diameter, and the speed 60 revolutions per minute, giving 83 rated H. P. with 80 lbs. steam pressure, and one-fourth cut off.

There are three independent submerged wrought-iron condenser tanks, each containing 7 865 lin. ft. of 1-in. pipe, and three wrought-iron brine tanks, insulated with ground cork and finished with pine, having a total capacity of 67 700 galls. and containing 35 788 lin. ft. of 1-in. pipe. The pipe coils in the condensers and brine tanks are arranged in sections with valves, so that any coil may be removed and cleaned or repaired without placing the tank out of commission. The

brine is pumped to the cold storage rooms by two Snow duplex steam pumps, having 14-in. steam cylinders, 12-in. water plungers and 14-in stroke.

Insulation.—All high-pressure steam pipes (that is, carrying a pressure of 100 lbs. above the atmosphere) are covered with magnesia sectional covering 2 ins. thick, and all low-pressure and exhaust pipes with the same kind of covering 1 in. in thickness. The brine mains have the patent covering of Macan & Company, of Philadelphia, consisting of 3 ins. of hair felt, in two layers of 1½ ins. each, breaking joint, each layer being coated with a preparation of gutta-percha, and the whole covered with waterproof paper and painted canvas. The insulation has proved very satisfactory. The two 6-in. steam mains from the boilers to the head-house, although they run a distance of 1 200 ft., of which 185 ft. is in the tunnel carrying at the same time two 8-in. brine mains, show no appreciable difference in pressure in the head-house, and the difference in temperature of the brine is but 3° between the the initial and return. No ice or moisture forms on the brine pipe covering throughout its entire length.

As a matter of interest, it may be stated that the average daily consumption of coal for the entire plant of the station from January 1st, 1894, to May 1st, 1895, was as follows:

1894.	Tons.	1895.	Tons.
January	30.3	January	46
February	37.1	February	52
March	32.4	March	42
April	28.7	April	35.8
May	33.7		
June	26.6		
July	32		
August	40		
September	30		
October	38		
November	40		
December	45		

It is to be noted that the large increase of coal consumption in August, 1894, is partially due to dirty boilers and partially to the fact

that steam was supplied for an ice plant placed in the power-house to furnish ice for use in passenger cars, etc. The various tests of boiler evaporation gave the following results, the first two having already been noted under boilers:

First.—February 25th, 1893, clean boilers, fires forced, 9.74 lbs. water from and at 212° Fahr. per pound of combustible.*

Second.—April 29th, 1893, clean boilers, fires not forced, 9.90 lbs. water from and at 212° Fahr. per pound of combustible.*

Third.—July 18th, 1894, dirty boilers, fires not forced, 8.62 lbs. water from and at 212° Fahr. per pound of combustible.†

Fourth.—July 19th, 1894, dirty boilers, fires not forced, 9.60 lbs. water from and at 212° Fahr. per pound of combustible.†

Fifth.—July 25th, 1894, dirty boilers, fires not forced, 9.38 lbs. water from and at 212° Fahr. per pound of combustible.‡

Plate IV, Fig. 1, is interesting as showing the work of construction of the building in progress. The end at Arch Street was being painted while the foundations towards Market Street were still being dug out, and the train-shed roof only partially erected. At the same time, the market under the train-shed floor was occupied and in use. Plate IV, Fig. 2, is an exterior view of the station building.

Cost of the Buildings.—As a general rule it is rather a delicate matter with the engineer or architect to make mention of the cost of the work under his charge, as it involves questions in confidence between himself and his client. The subject, however, is one of special interest to the professional man, and it is felt that no confidence is violated in giving the following general information.

The cost of the head-house proper, exclusive of heating, electric lighting, elevators, water supply, pumping, filters and other appurtenances to these special items, was $35.95 per square foot of superficial area, or 23.1 cents per cubic foot of content, computed between outside faces of exterior walls and from cellar floor to top surface of roof. The train-shed and lobby, including the foundations, the cold storage cellar and rooms, the tunnels, the market house with stalls and all fixtures, and the restaurant, but excluding brine pipes in cold storage rooms, electric lighting, heating, elevators and water supply, was $8.53 per

* Red ash pea coal, Lykens Valley.
† White ash buckwheat coal, St. Clair mine.
‡ White ash pea coal, St. Clair mine.

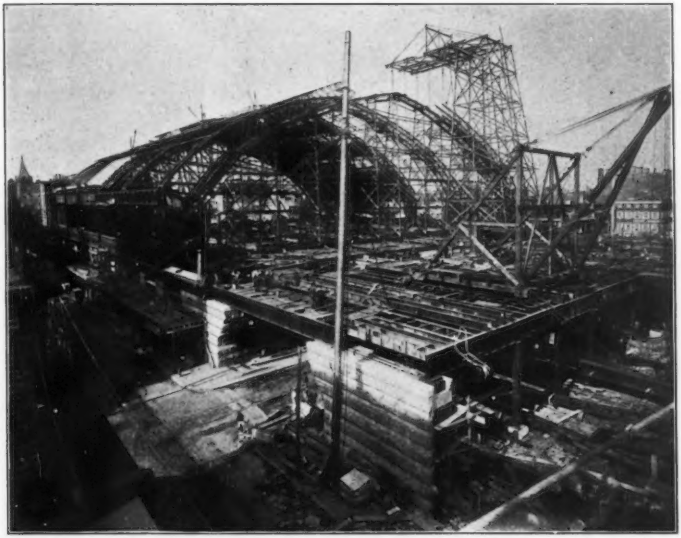


FIG. 1.

FIG. 2.

square foot of surface covered. The structural iron work of the roof to the train-shed cost $1 15 per square foot of surface covered.

There were 885 scale and 225 full-size drawings made for the buildings, including the Spring Garden Street station and the engine houses, as well as 500 drawings for the railroad work, a total of 1 610 drawings. There were over 7 000 blue prints made from these drawings for use on the work.

In the execution of this work by the firm of Wilson Brothers & Company as engineers and architects, John A. Wilson, M. Am. Soc. C. E., acted as chief engineer for the entire operation, taking particular charge of the railroad work, and having William H. Millard as principal assistant. He also superintended all of the construction, including the buildings as well as the railroad lines. Joseph M. Wilson, M. Am. Soc. C. E., and Henry W. Wilson, M. Am. Soc. C. E., together with Howard S. Richards as principal assistant, designed and had charge of the bridges, roof and all structural work. Henry A. Macomb and Joseph M. Wilson, with John J. Dull as principal assistant, designed and had charge of the architectural work. Charles G. Darrach, M. Am. Soc. C. E., with Robert C. Clarkson, Jun. Am. Soc. C. E., as principal assistant, designed and had charge of all the mechanical engineering work, including the electric lighting and refrigerating plants, and all other machinery.

APPENDIX I.

SPECIFICATIONS FOR THE EXCAVATION AND MASONRY ON THE PHILADELPHIA AND READING TERMINAL RAILROAD COMPANY'S LINES IN THE CITY OF PHILADELPHIA.

The structure of the Philadelphia and Reading Terminal Railroad (excepting where constructed of iron) will generally consist of two retaining walls parallel with the center line of the road, and abutment walls at the street crossings, built on the street lines. The area enclosed by these walls will be filled hereafter with material suitable for embankment. In special cases piers of masonry will be built to carry the iron superstructure. These walls will be built in the positions and of the heights shown by the maps and profiles, and of the thickness, form and dimensions shown by the drawings to be hereafter prepared to suit the various places. The profiles and drawings exhibited at the letting of the work are general ones, and will be modified by the engineers as occasion may require.

In addition to the masonry for the structure proper, there will be foundation piers for iron columns, masonry for street bridges over the railroad, etc., all of which are intended to be covered by this specification. In the case of foundations for columns, anchor bolts are to be built into the masonry, and cap-stones are to be provided as indicated by the detailed drawings.

There will be two distinct classes of masonry, viz.: first-class rock range work, which will generally be used for abutments, piers and foundations of columns; rubble work, which will generally be used for retaining walls.

The engineer will designate what class of masonry is to be used at each place, and the right is reserved to use either first-class masonry or rubble work in any position at the discretion of the engineer.

All materials used throughout must be the best of their respective kinds, and the entire work is to be constructed and finished in every part in a good, substantial and workmanlike manner, according to the drawings and these specifications, to the full extent and meaning of the same, and to the entire satisfaction, approval and acceptance of the engineer, and under the supervision and directions of such agent as he may appoint.

Alterations.—It is understood that the company shall have the right to make any alterations, additions or omissions of work or materials herein specified or shown on the drawings, during the progress of the work, that they may find to be necessary, and the same shall be acceded to by the contractor or contractors, and carried into effect without in any way violating or vitiating the contracts.

Also, that any disagreement or difference between the company and contractor, upon any matter or thing arising from these specifications or the drawings to which they refer, or the kind or quality of the work

required thereby, shall be decided by the engineer, whose decision and interpretation of the same shall be considered final, conclusive and binding upon both parties.

Care of Finished Work.—Particular care must be taken by the contractor of all the finished work as the walls progress, which work must be thoroughly protected from injury or defacement during the erection and completion of the walls.

Removal of Rubbish, Etc.—All refuse material and rubbish that may accumulate during the progress of the work is to be removed from time to time, as may be directed by the agent in charge; and on the completion of the work, the streets and grounds must be thoroughly cleaned up, and the surplus material and rubbish removed.

Risks, Blame, Etc.—The contractor is to assume all risks and bear any loss occasioned by neglect or accident during the progress of the work, until the same shall have been completed and accepted by the engineer. He is also to assume all blame or loss by reason of neglect or violation of state, city or district ordinances, laws or regulations, encroachments upon neighbors, or from any other cause.

The engineer shall have full power, at any time during the progress of the work, to reject any materials he may deem unsuitable for the purposes for which they are intended, or which are not in strict conformity with the spirit of these specifications. He shall also have the power to cause any inferior or unsafe work to be taken down and altered at the cost of the contractor.

Excavation of Foundations.—The excavation of foundation trenches shall be done as the work requires, and the materials taken from the trenches, excepting that needed for refilling alongside of walls, shall be deposited at such places, in the area enclosed by the walls, or elsewhere, as the engineer may direct from time to time.

The foundation trenches will be excavated at least 6 inches wider on each side than the width of the masonry, and to such depth as may be directed by the engineer. Generally, the sides of the foundation trenches will be excavated vertically, and the contractor must provide such shoring as may be necessary to prevent caving of the sides of the trenches until the masonry is built. In special cases where, in the judgment of the engineer in charge, the nature of the material or the special circumstances existing require that the sides of the trenches shall be sloped, they will be excavated in that way to the stakes given by the engineer. In all cases the width, depth and side slopes of the trenches will be regulated by the engineer, and no material excavated outside of the lines given by him will be paid for.

All old wells and privies found within the line of the road-bed must be thoroughly cleaned out and filled up with good material, and where such wells occur under walls, they must be also properly arched over.

When the foundation masonry has been built, the spaces between the walls and the sides of the excavation must be carefully and thoroughly refilled to the height of the adjacent surface.

All excavation of foundation trenches will be estimated and paid for by the cubic yard, measured in the excavation, which price will include refilling the trenches alongside the walls, the furnishing of timber for shoring, pumping water, the depositing and spreading of the excavated material, as may be directed by the engineer in charge, and all incidental work and expenses connected therewith.

Foundations.—Where good, solid, natural foundations can be had, the masonry will be built on the same. If, in the judgment of the

engineer, the character of the foundation requires it, concrete shall be used to prepare a foundation for the stone work. Such concrete shall be formed of an approved, hard, durable stone, broken into angular fragments of a size to pass through a 2½-in. ring, and to be screened. The concrete shall consist of broken stone, 6 parts; clean, sharp, coarse sand, 2 parts; and first quality Portland cement, 1 part.

The cement and sand are first to be spread in layers and thoroughly mixed dry in a box or on a platform provided for the purpose. This mixture is then to be removed to a box from time to time as required, and made into mortar, sufficient water being added to make a stiff paste, after which the broken stone is to be added with sufficient water to bring the mass to a proper consistency, the materials being manipulated as the water is added, until all are thoroughly incorporated, and each piece of stone is well coated with the mortar, and the broken stone distributed equally through the entire mass. This concrete must be placed in the foundation trench in layers not over a foot thick, filling the whole width of the trench. Each layer must be well rammed until a film of water appears on the surface, but not enough to make it quake.

The concrete must not be mixed in larger amounts than requires 1 barrel of cement at a time, and must be used as mixed, not being allowed to lie and then remixed with water. No concrete that has commenced to set will be allowed.

Masonry must not be laid on concrete until it has set firmly and becomes hard. Should special conditions require that foundations be otherwise prepared, the work shall be done as directed by the engineers.

Rubble Masonry.—All the masonry of retaining walls shall be rubble work, laid with cement mortar in irregular courses, and will consist of stones containing generally 12 cu. ft. each, so disposed as to make firm and compact work, and no stone in the work shall contain less than 4 cu. ft., except for filling up the interstices between the large blocks in the heart of the wall; provided, however, that in the upper part of the wall, where its thickness becomes less than 5 ft., the average size of the stones shall be from 6 to 8 cu. ft. to suit the thickness of wall. At least one-fifth of each face of the wall shall be composed of headers extending full size not less than 4 ft. into the wall (excepting where the wall is less than 5 ft. thick, when the headers shall extend across two-thirds of the width of the wall) so arranged that a header in one face shall be between two headers in the opposite face. When the headers from the two faces do not interlock, stones not less than 4 ft. long shall be laid transversely in the heart of the wall to connect the two opposite sides. If, in the progress of the work, an increase in the number of headers specified should be required by the engineer, such additional number as he shall designate shall be laid in the work. The corner-stones shall be neatly hammer-dressed so as to have horizontal beds and vertical joints.

Where the retaining walls join the abutment walls, the stones must be squared and jointed to ensure close contact, but the retaining and abutment walls will not be bonded together. The masonry must be accurately built to the lines and levels given by the engineer, and the exposed faces must be straight, true and smooth, without prominent or sharp projections of the rock or quarry face of the stone.

The stone used must be first-class Conshohocken stone, or stone of equal quality, to be approved by the engineer. It must be hard and durable, of good size and shape, with good natural beds suitable for

making first-class rubble work; no stone in the work to have less bed than face, and all must be carefully bedded on their broadest faces, and well bonded together.

The interior and exterior faces of the wall above ground shall have the joints thoroughly cleaned out for not less than 1 in. in depth, and they shall be pointed with Portland cement mortar.

Retaining walls are to be finished at top with coping as per drawings. The coping stones to be neatly dressed, carefully bedded in Portland cement mortar, with grouted joints, secured to wall by dowels, and to each other by clamps.

Drainage openings are to be made in walls, or pipes built in, as may be directed by the engineer.

First-Class Masonry.—Abutment walls and piers shall be first-class, rock-range masonry, of large-dimension stones laid in cement mortar and carefully grouted. The stone used to be Conshohocken stone, or stone of equal quality, to be approved of by the engineer. The stone to be accurately squared, jointed and bedded over their whole surface, and laid in courses not less than 12 ins. thick, nor exceeding 24 ins. thick, regularly decreasing in thickness from bottom to top of abutment. The stretchers shall in no case have less than 16 ins. bed, nor less bed than face, and shall generally be at least 4 ft. long. The headers shall be of similar size with the stretchers, and shall hold the size in the heart of the wall that they show on the face, and shall occupy at least one-fifth of the face of the wall. When the wall is too thick to admit of the headers interlocking, stones not less than 4 ft. long shall be placed transversely in the heart of the wall to connect the opposite sides. The stones for the heart of the wall must be of the same thickness as those in the face, bedded the same as the face stone, but not jointed, and must be well fitted to their places, the interstices being filled with sound stones. The abutments must be finished with neatly cut coping, as per drawings, and the whole work neatly pointed with cement mortar.

N. B.—The foundation masonry below ground will be of same quality and character as the masonry above ground.

Mortar.—The mortar used for all classes of masonry shall be fresh mixed, and composed of 1 part by measure of Portland cement of approved quality and 2 parts of clean, sharp sand. The cement and sand shall be thoroughly mixed together dry, and a portion of the mixture be worked up with water for immediate use, as may be needed from time to time. No cement mortar shall be used that has been mixed with water more than 10 minutes, and no cement mortar shall be worked over a second time.

The sand used must be sharp, clean and entirely free from mica, loam, clay or other impurities.

All cement used for mortar or grouting shall be first quality American, English or German Portland, and shall be subject to the tests described in the Standard Specification of Wilson Brothers & Co. for cements, hereunto attached, and which are hereby made a part of this specification.

General Conditions.—Particular care must be taken in selecting the stone for the exposed faces of the walls above ground. Masonry must not be laid in hard-freezing weather, and work left standing over winter must be covered up and protected. All masonry will be paid for by the cubic yard of 27 cu. ft., engineer's measurement, of actual cubic content, without regard to any measurers or trade rules or customs of measurement, and all measurements and calculations of quantities will

be made by the engineer in charge of the work. The price paid per cubic yard shall in every case include the furnishing of all materials and labor, all the expense of delivering the materials, and the cost of all scaffolding, shoring, derricks, tools, etc., and all expenses and risks of every kind.

Especial care must be taken, and every precaution used during the progress of the work, to protect the streets and to avoid injury or inconvenience to persons passing. Where the abutment or other walls front on streets, on the completion of each wall the sidewalk must be restored and repaved, and curbs reset (if they have been disturbed) and be left in good condition. Where any of the walls come close to adjoining properties, the necessary precautions must be taken to ensure the safety of adjoining buildings, and the foundation walls of such building must be underpinned if necessary to protect them. The contractor must assume all responsibility for injury to persons or property. When directed by the engineer, temporary openings must be arranged for in the walls to admit of the taking in of filling material for the embankment.

No charge shall be made by the contractor for hindrances or delay, from any cause, in the progress of any portion of the work in this contract, but it may entitle him to an extension of time, allowed for completing the work, sufficient to compensate for the detention, to be determined by the Chief Engineer, provided he shall give the engineer in charge immediate notice, in writing, of the cause of the detention.

Nor shall any claim be allowed for extra work, unless the same shall be done in pursuance of a written order from the engineer in charge, and the claim made at the first settlement after the work was executed, unless the Chief Engineer, at his discretion, should direct the claim, or such part as he may deem just and equitable to be allowed.

All of the work to be done in the best and most workmanlike manner, of approved materials, according to the plans and drawings, and everything necessary for the proper and complete execution of the said plans and drawings, whether the same may have been herein particularly specified or not, or indicated on the plans referred to, to be done and furnished in a manner corresponding with the rest of the work, as well, as truly and as faithfully as though the same were herein particularly described and specifically provided for.

Every part of the work to be executed under the direction and subject to the approval of the engineer, to whom all questions relating to the intent and meaning of the plans, drawings, specifications, or of the kind or quality of the materials and work required thereby, shall be referred, and his decision shall be final, conclusive, and without appeal.

Excavation of foundations will be paid for by the cubic yard.

All masonry, including coping, will be paid for by the cubic yard, the coping being measured in as part of the wall to which it belongs.

Concrete in foundations will be paid for by the cubic yard.

Special work that cannot be determined in advance, such as cleaning and arching privies and wells, underpinning foundations of adjacent buildings, etc., will be paid for at engineer's estimate, viz., cost, with 10% added for superintendence and use of tools.

PHILADELPHIA, February 24th, 1891.

SUPPLEMENTAL SPECIFICATIONS FOR ARCH BRIDGES OVER STREETS BETWEEN CALLOWHILL AND ARCH STREETS, ON THE LINE OF THE PHILADELPHIA AND READING TERMINAL RAILROAD.

Arch bridges are to be built according to the detailed plans furnished and under the specifications for the Reading Terminal masonry, dated February 24th, 1891, so far as the same will apply, the same being supplemented as hereinafter stated.

Arches proper to be of brick, as per drawings. The brick to be the best quality of straight, hard-burned, hand-made brick. No bats, salmon or soft brick of any grade will be allowed. The brickwork will be laid in cement mortar, with joints not exceeding $\frac{1}{4}$ in., and with such bond as the engineer may direct. The bricks at the time of laying to be well wet, the cement mortar to be thin and freshly mixed, the cross-joints to be carefully filled, and each course to be thoroughly grouted. The several courses of brick at the crown, forming the key, to be laid close, with very thin joints, and thoroughly grouted.

The face of the arch will be formed of ring stones composed of alternate long and short bond stones, not less than 3 ft. and 18 ins. respectively, neatly cut to a pattern. Ring stones to be of Leiperville, Conshohocken or Port Deposit stone, as directed. The exposed face on the facade to be quarry face with a draft line all round each stone. Parapet or facade masonry to be first-class rock range work, as specified in the general specifications for piers and abutments. Similar masonry to be used on the street fronts of abutments, with the stones forming the continuation of the arch in the interior of the walls, to be arranged as shown on drawings, all neatly and accurately cut, coping to be as per drawings.

The foundations below the first-class work will be concrete and rubble work as per drawings. The backing over the arch and portions of abutments above the arch line to be rubble work as per drawings, the stones where they join the brickwork to be laid in close to the arch. All the rubble work to be first class, closely laid, of large stones, and thoroughly grouted. The whole work to be laid in mortar composed of 2 parts of clean sharp sand and 1 part of best American Portland cement, of approved quality, except brickwork, which shall be laid in mortar of best imported Portland cement. Bar sand to be used for mortar in brickwork. Grout to be of same cement and sand, and with same proportions.

The whole work to be finished in a good and workmanlike manner, so as to be impervious to water. All exposed faces of brick and stone work to be neatly pointed with Portland cement mortar. Cast-iron drain pipes are to be built in the walls as directed, and the upper surface of masonry to be covered with two layers of Neuchatel asphalt covering, each layer 1 in. thick.

The price paid for the masonry per yard will be for all complete, from the bottom of the excavation (including concrete), and will cover centering and all incidental expenses, except the drainage pipes and asphalt covering, which shall be paid for at engineer's estimate.

PHILADELPHIA, August 3d, 1891.

APPENDIX II.

PHILADELPHIA AND READING TERMINAL RAILROAD.

The iron construction on this road will consist of the following structures:

First.—Plate-girder deck bridges over streets from Arch to Callowhill, for four or more tracks, as shown by the detailed plans of the road.

Second.—On the branch from Callowhill near Twelfth Street, to Broad and Noble Streets, deck plate-girder construction for two tracks, as shown by general drawings, from Callowhill Street to a point west of Twelfth Street; iron construction of columns and girders to Thirteenth Street, and a plate-girder with floor on lower chords over Thirteenth Street.

Third.—From near Eleventh and Callowhill Streets, to a point on Ninth Street north of Green, iron construction of columns and plate-girders for two tracks, with a through truss bridge over Spring Garden Street, and plate-girder with track on lower chords over Green Street; all as shown on the general drawings.

The several structures must be designed to suit the particular localities which they are to occupy, and for the number of tracks required at each place, and must include sidewalks on each side of the structure for trainmen. All bridges and portions of iron construction over streets must be provided with acceptable screens, arranged as per general drawings, to guard the view from the streets of passing trains, and approved system of deadening for floors must be provided for the full width between house lines, over all streets. All plans must conform to the requirements of the ordinance of City Councils permitting the construction of the road, and are subject to the approval of the Department of Public Works of the City of Philadelphia. The profile of the road will show the elevations of track and the clearances required at each street. General drawings and specifications will be furnished on application to the chief engineer.

The contractor for the iron work must furnish anchor bolts and attachments for building into the masonry of column foundations, with drawings for locating same. He must also test for himself, on the ground, all measurements of spans of bridges, and distances between column foundations, construct the iron work to conform to same, and be responsible for any errors of measurements or variations that may be found in the iron work when same comes to be erected.

Where the line of road is on a curve, the proper elevation of the outer rail (to be established by the engineer) is to be arranged and provided for, the elevation being tapered off on the tangent as may be directed by the engineer.

The bridges and iron structure are to be finished complete in every respect, including the wooden floor system, sidewalks and railings, ready for laying the rails of the track. All iron work to be painted with three coats of best white lead in linseed oil to tints as may be

directed by the engineer. It must be understood that this painting is to be in addition to the priming coat of paint provided for in the iron specification. All track timbers to receive three coats of red oxide of iron paint in linseed oil. Appropriate hand-railings to be provided at all bridges and on iron construction for the protection of trainmen using the sidewalks.

All materials used throughout must be the best of their respective kinds, all of the work to be done in the best, most substantial and workmanlike manner, according to the plans, drawings and these specifications, to the full intent and meaning of the same, and everything necessary for the proper and complete execution of the said plans and drawings, whether the same may have been particularly specified or not, or indicated on the plans referred to, to be done and furnished in a manner corresponding with the rest of the work, as well, as truly and as faithfully as though the same were herein particularly described and specially provided for.

Every part of the work to be executed under the direction and to the entire satisfaction, approval and acceptance of the engineer, and under the supervision of such agent as he may appoint.

Risks, Blame, Etc.—The contractor is to assume all risks and bear any loss occasioned by neglect or accident during the progress of the work, until the same shall have been completed and accepted by the Engineer. He is also to assume all blame or loss by reason of neglect or violation of state, city or district ordinances, laws or regulations, encroachments upon neighbors, or from any other cause.

Especial care must be taken, and every precaution used during the progress of the work, to protect the streets and to avoid injury or inconvenience to persons passing. The contractor must assume all responsibility for injury to persons or property.

Alterations.—It is understood that the company shall have the right to make any alterations, additions or omissions of work or materials herein specified or shown on the drawings, during the progress of the work, that they may find to be necessary, and the same shall be acceded to by the contractor or contractors, and carried into effect without in any way violating or vitiating the contracts.

The engineer shall have full power, at any time during the progress of the work, to reject any materials he may deem unsuitable for the purposes for which they are intended, or which are not in strict conformity with the spirit of these specifications. He shall also have the power to cause any inferior or unsafe work to be taken down and altered, at the cost of the contractor.

No charge shall be made by the contractor for hindrances or delay, from any cause, in the progress of any portion of the work in this contract, but it may entitle him to an extension of time allowed for completing the work sufficient to compensate for the detention, to be determined by the chief engineer, provided he shall give the engineer in charge immediate notice in writing of the cause of the detention.

Nor shall any claim be allowed for extra work unless the same shall be done in pursuance of a written order from the engineer in charge, and the claim made at the first settlement after the work was executed, unless the chief engineer, at his discretion, should direct the claim, or such part as he may deem just and equitable, to be allowed.

Any disagreement or difference between the company and contractor upon any matter or thing arising from these specifications or the drawings to which they refer, and all questions relating to the intent and meaning of the plans, drawings, specifications, or of the kind or

quality of the materials and work required thereby, shall be referred to the engineer, and his decision shall be final, conclusive and without appeal.

Parties making proposals for the iron work must furnish sample drawings, showing the general arrangement and design which they propose to use, and all designs and drawings must be subject to the approval of the chief engineer.

Proposals for the work will be made for the several structures erected, in place, complete, ready for use, and prices are to be named per foot lineal of the several structures, the length to count from center to center of end pins for open truss bridges, and from out to out for plate-girders. The masonry of abutments, piers and column foundations will be provided by the railroad company.

Bids must specify the earliest time of completion if the work is commenced forthwith.

The company does not bind itself to accept the lowest or any bid.

MAY 1ST, 1891.

APPENDIX III.

SPECIFICATION FOR THE FURNISHING, MANUFACTURE AND ERECTION OF STRUCTURAL IRON WORK FOR THE TRAIN-SHEDS, ETC., OF THE PASSENGER STATION OF THE PHILADELPHIA AND READING TERMINAL RAILROAD COMPANY AT TWELFTH AND MARKET STREETS, PHILADELPHIA.

Several contracts may be made under these specifications for different parts of the work, in which case special instructions to bidders will be issued, with a list of drawings pertaining to the particular letting and explanatory thereof, which special instructions and drawings will be considered part of this specification.

Figured dimensions shall in all cases be taken in preference to scale measurements.

Additional Drawings.—Additional detail drawings will be furnished in exemplification of the work from time to time as they may be required, and it is to be distinctly understood that all such additional drawings shall be of equal force with those which are herein specifically cited, and the said additional drawings are to be considered as virtually embraced within and forming part of this specification.

General Conditions.—This specification is intended to embrace all the work as specifically stated in the several instructions to bidders, complete and ready for occupancy, the whole of said work to be comprised within this specification for any contract or partial contracts that may be made for the construction of the same.

All materials used throughout must be the best of their respective kinds, subject to the inspection and approval of the engineers and architects. The entire work provided for in this specification is to be constructed and finished in every part in a good, substantial and workmanlike manner, according to the accompanying drawings and this specification, to the full intent and meaning of the same, and everything necessary for the proper and complete execution of the plans and drawings, whether the same may have been herein particularly specified or not, or indicated in the plans referred to, to be done and furnished in a manner corresponding with the rest of the work, as well, as truly and as faithfully as though the same were herein particularly described and specifically provided for.

The general detail drawings of the structural iron work will be furnished to the contractor, who is to take the same and from them to make his own special shop drawings. These shop drawings must conform to the general detail drawings in every particular, and are to be submitted to the engineers and architects, and to be approved by them before the work is proceeded with; and said approval shall in no way authorize any change from the said general drawings, unless such change has been specially agreed to and made in the general drawings.

Four copies of each shop drawing are to be furnished to the engineers and architects for use in their office.

The contractor is also to verify all drawings furnished him, so far as relates to the dimensions and the interworking of the various parts, and he is to be responsible for the accuracy of his own shop drawings in all their details.

Every part of the work to be executed under the direction and to the entire satisfaction, approval and acceptance of the engineers and architects, and under the supervision and direction of such agents as they may appoint.

All questions relating to the intent and meaning of the plans, drawings, specification, or of the kind or quality of the materials and work required thereby, shall be referred to the engineers and architects, and their decision shall be final, conclusive and without appeal.

The contractor must be responsible for all patents, and must protect the railroad company against any and all claims on account of the use of the same.

Access must be allowed to the engineer and his assistants to the contractor's working drawings and shops for examination of details.

No charge shall be made by the contractor for hindrances or delay, from any cause, in the progress of any portion of the work in this contract, but it may entitle him to an extension of time allowed for completing the work, sufficient to compensate for the detention, to be determined by the engineers and architects, provided he shall give the engineer in charge immediate notice, in writing, of the cause of the detention.

In the case of subcontractors, the specifications are fully binding on them in every respect, and free access and information is to be given by them for thorough inspection of material and workmanship, and all required test pieces, etc., properly shaped, are to be provided as may be requested, without charge.

Any exceptional increase of cost of inspection of material due to location of works, must be borne by the contractor.

All shipments of material not properly inspected and passed are at the risk of the contractor.

The contractor must test the accuracy of the measurements as given by drawings with the actual foundations as provided on the ground for the structural iron work, so as to satisfy himself of their correctness before proceeding with the work.

The engineers and architects shall have full power at any time during the progress of the work to reject any materials they may deem unsuitable for the purposes for which they are intended, or which are not in strict conformity with the spirit of this specification. They shall also have the power to cause any inferior or unsafe work to be taken down and altered at the cost of the contractor.

Alterations.—It is understood that the company shall have the right to make any alterations, additions or omissions of work or materials herein specified or shown on the drawings, during the progress of the construction, that they may desire, and the same shall be acceded to by the contractor or contractors and carried into effect without in any way violating or vitiating the contracts. If any such changes are made, the value of the same shall be decided by the engineers and architects, who shall make an equitable allowance therefor, and shall add the amount of said allowance to the contract price for the work if the cost of the work has been increased, or shall deduct the amount from the contract price if the cost of the work has been lessened, as

they, the said engineers and architects, may deem just and equitable.

Also, that the railroad company will pay for no extra work or materials, unless ordered by them or their engineers and architects, with their approval.

Also, that any disagreement or difference between the company and contractor, upon any matter or thing arising from this specification, or the drawings to which it refers, or the kind or quality of the work required thereby, shall be decided by the engineers and architects, whose decision and interpretation of the same shall be considered final, conclusive and binding upon both parties.

Care of Finished Work.—Particular care must be taken by the contractor of all the finished work as the building progresses, which work must be covered up and thoroughly protected from injury or defacement during the erection and completion of the building.

Removal of Rubbish, Etc.—All refuse material and rubbish that may accumulate during the progress of the work must be removed from time to time, as may be directed by the agent in charge, and on the completion of the work, the building, streets and grounds must be thoroughly cleaned up, and the surplus material and rubbish removed.

Risks, Blame, Etc.—The contractor is to assume all risks and bear any loss occasioned by neglect or accident during the progress of the work, until the same shall have been completed, and accepted by the engineers and architects. He must properly protect any pavements of this and adjoining properties during the progress of the work, and make good any injuries that may have occurred to any adjoining building in consequence of or during the erection of this work. He is also to assume all blame or loss by reason of neglect or violation of city, district or state ordinances, laws or regulations, encroachments upon neighbors, or from any other cause.

Permits, Surveys, Etc.—The contractor must pay for all permits, surveys, inspectors' fees, or any other charges from borough, city, county or state officers.

Cast-Iron Work.

The cast-iron work to be true and sound, free from flaws and defects of any kind, the material good and tough and the lines corresponding exactly with the drawings. No rough or crooked castings will be accepted. All bolt and pin holes must be accurately drilled; all abutting surfaces must be planed, if necessary to insure even bearings and neat, close fittings, and the work must be properly fitted and erected.

Wrought Iron.

All wrought iron shall be of American manufacture.

All iron to be used in the tensile members of open trusses, laterals, pins, bolts, etc., must be double-rolled after and directly from the muck bar (no scrap will be allowed), and must be capable of sustaining an ultimate stress of 52 000 lbs. per square inch on a full section of test piece with an elastic limit of 26 000 lbs. per square inch and a minimum stretch of 20% measured after breaking in length of 8 ins.

All wrought iron not included under above head must be tough, fibrous, uniform in quality throughout, free from flaws, blisters and injurious cracks, and must have a workmanlike finish. It must be capable of sustaining an ultimate stress of 48 000 lbs. (excepting for plates over 24 ins. in width, which may be 46 000 lbs.) per square inch

on a full section of test piece, with an elastic limit of 26 000 lbs. per square inch.

All iron to be used in tension or subjected to transverse stress (except web-plates), must have a minimum stretch, on a length of 8 ins., of 15% measured after breaking.

All iron to be used in compression and for web-plates, of width not exceeding 24 ins., must have a minimum stretch of 10% on a length of 8 ins. measured after breaking.

All iron for web-plates exceeding 24 ins. in width, must have a minimum stretch of 5% measured in length of 8 ins.

When tested to the breaking, if so required by the engineer, the links and rods must part through the body and not through the head or pin hole. Such tests must be at the expense of the contractor when the requirements of these specifications are not complied with.

All tension wrought iron, if cut into testing strips 1½ ins. in width, must be capable of resisting without signs of fracture bending cold by blows of a hammer, until the ends of the strips form a right angle with each other, the inner diameter of the curve of bending being not more than twice the thickness of the piece tested. The hammering must be only on the extremities of the specimens, and never where the flexion is taking place. The bending must stop when the first crack appears.

All the tension tests are to be made on a standard test piece, of 1½ ins. in width, and from ½ to ¾ in. in thickness, planed down on both edges equally, so as to reduce the width to 1 in. for length of 8 ins. Whenever practicable, the two flat sides of the piece to be left as they come from the rolls. In all other cases both sides of the test pieces are to be planed off.

All plates, angles, etc., which are to be bent in the manufacture, must, in addition to the above requirements, be capable of bending sharply to a right angle, at a working heat, without showing any signs of fracture.

All rivet iron must be tough and soft, and pieces of the full diameter of the rivet must be capable of bending until the sides are in close contract, without showing fracture on the convex side of the curve.

Pins of 4½ ins. diameter or less may be rolled iron, but those of greater diameter must be forged.

All workmanship must be first class; all abutting surfaces, except flanges of plate girders, must be planed or turned, so as to insure even bearings, taking light cuts so as not to injure the end fibers of the piece, and must be protected by white lead and tallow. Abutting members must be brought into close and forcible contact when fitted with the splice-plates, and the rivet holes punched ¼ in. less in diameter and reamed in position before leaving the works; the plates being marked so as to go in the same position in erecting. Web-stiffeners shall be milled at the ends to make exact and tight fit to the flange angles.

The ends of all track stringers and other framed members are to be milled off to an exact length and in the direction required by the angle of the framing.

Generally the use of bolts instead of rivets will not be permitted, unless they are turned conical and the holes reamed to fit them.

Rollers must be turned and roller-beds planed.

Rivet holes must be carefully spaced and punched and must in all cases be reamed to fit where they do not come truly and accurately opposite, without the aid of drift pins. Rivets must be machine-driven wherever possible, and the machines must be such as will

retain the pressure on the rivet after the upsetting is completed. Rivets must completely fill the holes and have full heads, and be countersunk when so required.

Compression members must be straight and free from kinks or buckles in the finished piece.

Eye-bars and rods shall have no welds except in the case of forming loops for counters, laterals or sway rods. The heads of eye-bars and thickening for screw ends to rods must be made by upsetting, forging or rolling. Eye-bars must be perfectly straight before boring, the hole must be in the center of the head, and on the center line of the bar. Whenever links are to be packed more than $\frac{1}{8}$ in. to the foot of their length out of parallel with the axis of the structure, they must be bent with a gentle curve until the head stands at right angles to the pin in their intended position, before being bored; suitable blocking pieces being used to keep them in proper position during the operation of boring.

All pin holes in pieces which are not adjustable for length must be accurately bored at right angles to the axis unless otherwise shown in the drawings, and no variation of more than $\frac{1}{64}$ in. will be allowed in the length between centers of pin holes. All pieces must be at equal temperatures when bored, and those belonging to the same panel, when placed in a pile, must allow the pin at each end to pass through at the same time without forcing.

Pins must be carefully turned, perfectly finished and straight, and when driven in must have pilot nut to preserve threads. No variation of more than $\frac{1}{32}$ in. will be allowed between diameter of pin and pin-hole.

In the case of bolts a variation of $\frac{1}{16}$ in. will be allowed between diameter of bolt and hole.

Thickening washers must be used whenever required to make the joints snug and tight.

The contractor must punch all holes that may be required in the structural iron work for attachment of other portions of the structure.

PAINTING.

Material standing out before manufacture must be protected from rusting by pure raw linseed oil, applied when temperature of iron is 60° (Fahr.) or over. All inaccessible surfaces must be painted, before riveting up, with one heavy coat of pure red lead in pure raw linseed oil. All work after manufacture to be given one coat of pure raw linseed oil applied to iron of temperature of 60° or over, and thoroughly worked into all joints and openings. All parts that are inaccessible after erection must have two coats of pure red lead in pure raw linseed oil, at site before erection.

All iron after erection must have one good coat of pure red lead in pure raw linseed oil.

All iron to be scraped clean from scale before oiling or painting.

DISCUSSION.

Mr. Darrach. C. G. DARRACH, M. Am. Soc. C. E.—The speaker said in amplification of the author's statements concerning the electrical installation, that the summer load on the incandescent dynamos is equivalent to 55 kilowatts, about 74% of the total load of one of the dynamos in the head-house, so that the plant is running quite economically.

The cold storage rooms are kept very free from moisture and vapor by reason of the numerous air locks. Eggs have been kept perfect, and sold and eaten as fresh after remaining 14 months in storage, and the speaker recently ate an apple which had been in cold storage for eight months and was perfect, without a sign of any defect whatever. On June 17th, 1895, the following temperatures were taken: Outside air, 76°; in the cold storage cellar surrounding the rooms, 68°; in the first air lock, 56°; in the second air lock, 50°; in the third air lock, 44°; in the fourth air lock or lobby to a freezing room, 34°; in the freezing room 3° Fahr. The temperature of the rooms is regulated to suit the materials stored; butter is kept at 20°, eggs and apples at a little above the freezing point, and meat at 33° to 34°.

During the summer, with brine at an initial temperature of 3° Fahr. the following ratio of brine cooling surface to net cubic contents maintains the temperatures mentioned in the rooms. The freezing rooms have side pipes in addition to the overhead pipes.

Cooling surface per cubic foot. Square feet.	Temperature, Fahr.	Kind of storage.	REMARKS.
0.082	32°	Meats	Compartment room accessible to tenants.
0.065 to 0.04	29° to 33°	Meats	Transient, controlled by superintendent.
0.033	33°	Eggs	Long storage, controlled by superintendent.
0.033	33°	General	Long storage, controlled by superintendent.
0.057	20°	Butter	Long storage, controlled by superintendent.
0.27	3° to 4°	Freezing	Long storage, controlled by superintendent.

The 8-in. mains through which the brine circulates at a velocity of about 2 ft. per second lose only about 3° between the initial point and the return, although their length is about 1 200 ft., of which 600 ft. is in an atmosphere with a temperature of 95° to 100° Fahr.

CORRESPONDENCE.

Mr. Wagner.

SAMUEL TOBIAS WAGNER, M. Am. Soc. C. E.—It must be remembered that at the time the train-shed described in the paper was constructed, it was the greatest single span train-shed in the world. As a roof, however, it had been eclipsed by the trusses of the Machinery Hall at the Paris Exposition of 1889, with their span of 364 ft. 2 ins., center to center of end pins, and by those of the Manufactures and Liberal Arts Building for the World's Columbian Exhibition at Chicago, with a span of 368 ft. center to center of end pins. Since its construction it has also been compelled to rank as second in the class of train-sheds by the roof of the Broad Street station of the Pennsylvania Railroad at Philadelphia.

The principal dimensions of the largest train-sheds in existence are as follows:

	Pennsylvania Railroad, Philadelphia.		Philadelphia and Reading Railroad, Philadelphia.		Pennsylvania Railroad, Jersey City.		Midland Railway, London, England.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Span of roof trusses, c. to c. end pins	300	8	259	8	252	8	240	0
Clear height at center	100	4	88	0	86	0	100	0
Width, out to out	304	0	266	6	256	0		
Length, out to out	598	0	506	8	652	6	600	0
Number pair of roof trusses	10		11		12			
Number of tracks	16		13		12		*10	

* Including 25 ft. roadway.

The practical construction of a roof of this magnitude was not undertaken without the most careful consideration and thought, especially as it was required that the chords of the trusses should be curved to the given radii instead of being straight between panel points, and it is believed that no other roof approaching it in magnitude has ever been constructed to the exact curves required by the drawings. Curves in shop construction are always extremely difficult to work with in order to insure accuracy in results, especially when in the same half truss there are five different radii to deal with, and compound curves in some of the individual sections into which the truss is divided for shipment. In order to insure the best workmanship and eliminate all chance of error, these conditions made it practically imperative

Mr. Wagner. that each half truss should be assembled by itself in the shop, all members being fitted to place and match marked. It will be remembered that in the case of the Forth Bridge in Scotland, practically the same method of procedure was adopted wherever the curved members of the truss occurred.

Curves in individual pieces offer no special difficulties, but whenever they form component parts of a whole, as in the case in discussion, the problem assumes a new and more serious aspect. Great care was observed in making the templets for the trusses and the best seasoned lumber was carefully selected and prepared. A complete duplicate set was made in case of accident and for the comparison of the working templets from time to time as the work progressed.

A space was prepared on the large floor of the bridge shop of the Phœnix Iron Company, covered with skids about 8 ft. apart, and generally radial to the chords of the truss. This space was sufficient to receive one-half of the truss. After the floor was prepared, the chord between the centers of pin-holes was calculated and laid off very carefully, the terminal points being established very accurately. From each of these points, by means of chords and deflection angles and using an engineer's transit, each panel point on the top chord of the truss was laid out, half of the truss being laid out from each end to insure accuracy. These lines checked within $\frac{1}{16}$ in. at the center panel point. The points were calculated to the back of the angles forming the top chord. After they were located the templets were placed on them and no discrepancy was found, thus forming a satisfactory check. Cast-iron chords with vertical lugs were then fastened to the skids, which were fastened solidly in place on the floor and the lugs set a given distance from the back of the chord angles. Hardwood blocks, bolted to these lugs, were used afterward to adjust for thickness of cover and splice plates. A series of points was thus established, which was used for reference in the future for each half truss. The method of procedure was follows:

Each half truss was divided into eight sections for shipment, marked from *A* at the heel of the truss to *H* at the peak. Sections *A* and *H* were riveted up and placed exactly in position on the skids. The chords of the remaining sections, which were of T shape, composed of a 12-in. vertical plate, two 6 x 6-in. angles and 14-in. covers, were riveted up, and all joints in the half truss faced but two; these joints were left unfaced for adjustment. The chords were then put in position on the skids, the top chords bearing against the hardwood blocks, and the diagonal and radial members fitted to place with the splice plates. All projecting cover plates over the splices on the tension chords were left blank and were drilled in place to insure good workmanship. No holes whatever were punched at the connections, where there was any likelihood of their not matching when assembled. All holes were then

reamed in place, and enough rivets driven by hand to insure against any motion when the truss was taken apart. Before taking it apart the pin holes were laid out and all loose pieces carefully match marked. Each section was then riveted by power, and finished in the usual way. Mr. Wagner.

On account of the curve required in the trusses, all web plates forming the chords had to be curved on edge. This was done on the straightening plate of the rolling mill, the straight edge on this plate being replaced by wrought-iron forms forged to the proper radii. This was done so successfully with the initial heat from the rolls, that no further work was necessary. The angles were all curved cold under a cam press. In some cases it became necessary to slightly recurve them after they were punched. No special work was required upon the purlins or the side trusses; the jack rafters, however, having the same curve as the top chord of the main trusses, were rather more difficult to handle, on account of the necessity of having the open holes for attachment to the purlins at the proper angle. These were assembled in the usual way and the holes for these connections set, in each case, by full-length templets. The fact that there was no trouble in the field in making any of these difficult connections showed the wisdom of this method of construction.

The facilities for erection were excellent. The plant consisted of a falsework upon which the arch was assembled, and a traveler framed together to make a single machine. The falsework extended the entire inside width of the train shed, and filled the space completely between the floor and the lower chord of the trusses. It was 17 ft. 9 ins. wide, center to center of legs at the base, and 5 ft. at the top of the cap, thus giving sufficient width to assemble the pair of trusses with their bracing upon the top. The legs consisted of 6 x 6-in. timbers, thoroughly braced in both planes by 2 x 8-in. and 2 x 6-in. pieces. Fourteen lines of rails ran longitudinally through the train-shed, and the falsework rested upon them by means of wheels 18 ins. in diameter, thus enabling the whole structure to be moved longitudinally. The traveler, about 126 ft. in total height and 40 x 28 ft. in plan on the level of the floor, was arranged as part of the falsework and rested upon the timbers forming its base. It was capable of motion in a transverse direction, and, as a part of the whole erection machine, could be moved longitudinally simultaneously with the falsework. It was provided with an overhanging top, which spanned two pairs of trusses, and was counterbalanced on the lower platform by means of two hoisting engines, their boilers, and 45 000 lbs. of ballast to prevent any overturning. The main posts were 8 x 8 ins., the back stay was 6 x 8 ins., with two rods 1¼ ins. square. The bracing was 2-in. plank, 6 to 8 ins. in width, thoroughly fastened.

The method of operating the falsework and traveler was as follows:

Mr. Wagner. The sections of the arch trusses were erected in pairs and braced together as fast as they were put in place, the connections being bolted. This operation was continued until the peak was reached, when the top pin was driven, completing the whole span. The purlins and jack-rafters, with the ventilator frame, were then placed in position, and riveting begun when all the joints were in place and had their full bearing. The time required to move the falsework from one pair of trusses to another, a distance of 50 ft. 2 ins., was about 40 minutes. The construction and erection of this shed was done by the Phœnix Bridge Company.

Mr. Wilson. JOSEPH M. WILSON, M. Am. Soc. C. E.—The author desires to state, in further explanation of the construction of the head-house, that the lower portion of the building, from the nature of things, almost necessarily became a fire-proof construction, the apartments being very large and the floors paved with marble or cement. The upper part of the structure is really something more than "of slow-burning construction" as that term is generally understood. The carrying framework is entirely of iron and steel, protected from the effects of fire by mackite, and the floors have no wooden girders, but consist of 3-in. planks, tongued and grooved, fastened to nailing strips on rolled steel beams and finished with 1-in. flooring boards on the top, the whole being thoroughly protected underneath by mackite. The partitions are of solid mackite. It will be seen that the only exposed wood is the upper surface of the floor which is required in the office rooms, the sash, and the doors and frames. The entire construction can therefore almost be classed as fireproof.